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THE HYDROLOGY OF PREHISTORIC FARMING SYSTEMS IN A CENTRAL ARIZONA ECOTONE

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PREFACE

Objective

The Central Arizona Ecotone Project was conceived as an interdisciplinary study of man's adaptation to a selected portion of the semi-arid Southwest. Hydrologists, geologists, biologists and archaeologists participated in the project, with the latter discipline acting as the integrating mechanism for all disciplines.

The test locality was chosen for its topographic, environmental and cultural diversity. Located in south-central Arizona, the test site is situated south of the Mogollon Rim. It encompassed three topographic situations: the Mesa-Canyon complex to the north; the transition zone of the central portion; and the Basin and Range Complex to the extreme south. The area comprises both the Upper and Lower Sonoran Life Zones, with the transition Complex displaying a blending of both life zones, to such a degree that initially it was described as an "ecotone."

It was felt that the only way to adequately understand such a large and diverse topographic and environemntal situation was through the use of remote sensing data. While the

archaeologists realized that orbital imagery would not permit visual interpretation of prehistoric sites other scientists would be able to use the data, especially as pertains to mapping and land use studies. Remote sensing data was supplied by the NASA Skylab missions (SL2, SL3, SL4) in the S190A, S190B and S192 format. High altitude coverage, from U-2 overflights of the test area, was secured and used as a comparative format for the Skylab and low-altitude fixed wing aircraft coverage. Each type of imagery was examined by each discipline in the project, and each photographic format was compared one to another.

Scope of Work

Because of the diversity of not only the test site, but the disciplines involved specific tasks were assigned to each discipline after long-range goals were formulated for the project as a whole. The goals were to define the environmental settings of the test area, and in doing so define the adaptations made by both the prehistoric and historic populations of the test area. Additionally, keys were to be derived which would most successfully aid in the interpretation of all imagery.

The specific goals for each discipline naturally many times overlapped (see Sec. 1.1 for specific goals). The

hydrology-geology section was to define not only the geometric characteristics of selected small drainage basins but was to identify utilized prehistoric canal systems. The biologists were to define the boundaries of the various biological communities, and delineate plant-water relationships. The archaeology discipline was to determine how prehistoric man adapted to his environment, and in doing so, the role of the land use/water management systems.

Each discipline in addition was to define the most useful type of imagery for its purposes. In doing so, certain questions were asked by each discipline of each type of format. For example the hydrologists consistently examined imagery with the intent of determining stream order number and how useful type of imagery was for the delineation of drainage networks.

Conclusions

The project, for the most part, successfully accomplished each of its goals. The lateness in receiving the orbital data necessitated the use of ground truth operations prior to photographic analysis as had been originally planned. Nonetheless, this did not greatly hinder operations. The lack of suitable data from two Skylab missions (SL2 coverage was obscured by cloud cover, and SL3 was off target) did, however, obfuscate

the possibility of comparing the different missions. The lack of early data hurt the biologists especially, as those two missions would have shown the test area during the flowering and fruiting seasons. As it was the biologists had to rely almost solely on SL4 coverage, which was taken during the dormant season.

However, with what coverage was available, it was possible to determine which formats were the most useful. All disciplines concluded that S190B, color or color infrared, was the most adequate Skylab coverage for the project needs. However, the most useful photographic coverage over all was the high altitude U-2 black and white photographs. Lower altitude imagery aided the archaeologists most in terms of site location, and was of little use to the other disciplines.

Summary of Recommendations

The Central Arizona Ecotone Project summarizes its recommendations for the use of orbital and lower altitude imagery as follows.

1) That if orbital imagery is to be used by biologists, it is a necessity that it encompass at least the fruiting and flowering seasons of the year,

2) It has been found that S190B is the most useful Skylab format, for multidisciplinary projects, if

used in conjunction with U-2 black and white imagery. The use of orbital imagery demands ancillary lower altitude coverage as a crosscheck.

3) In the utilization of orbital imagery by multi-disciplinary project limited ground truth operations are advisable prior to photographic analysis. This enables the project team to familiarize themselves with pertinent landmarks, and the general topography of any given test locality.

4) That archaeology in the final analysis, has the most need for orbital data analysis. By utilizing that medium the archaeologist receives ancillary geologic, hydrologic and biological data about any given test locality, while not necessarily having to field specialists in each of those disciplines.

5) As a corrolate of #4, the use of orbital imagery in the project demanded a much closer working relationship from all participants than might normally be anticipated. The questions answerable by the imagery lent themselves to the basic integration of all sub-discipline interests into a cohesive unit.

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1.0 INTRODUCTION

The Central Arizona Ecotone Project (CAEP) is an interdisciplinary research project designed to examine the problem of prehistoric land use and water management in a carefully selected area of the semi-arid Southwest. This was to be accomplished through utilization of various formats of Skylab imagery as well as collateral remote sensing techniques and ground truth activities. The project team members included archaeologists, hydrologists, geologists, and biologists. A major methodological focus of the project was the utilization of **orbital** (i.e., earth-orbiting satellite) remote sensing techniques as a common data base for the various project team members and the scientific disciplines they represented. Remote sensing data were supplied both by NASA and the United States Geological Survey. All coverage analyzed was compared one to another and with results derived from ground truth operations.

The image coverage afforded a hypothetical opportunity to do extensive areal mapping, especially as regards major

vegetation communities, physiography and hydrology. The practical application of high altitude imagery in the identification of specific archaeological materials remains questionable. However, the imagery did provide an opportunity for exploring various techniques which could aid both the archaeologist and natural scientist in the analysis of prehistoric exploitation of the study area. By doing so, it was hoped that recommendations could be made regarding the modern exploitation of the same area.

As a point of information, it should be noted that in the original proposal submitted to NASA the Principal Investigator suggested:

> Although obviously most individual archaeological sites will be of a size which would preclude their being susceptible to mapping by space photography, the entire region has to be defined and separated from the neighboring plateau country to the north and desert country to the south. There are other cultural-hydrologic-soil features which can be dealt with effectively for the entire region only by small scale mapping. For instance, although the region is semi-arid climate, the runoff characteristics will vary from basin to basin depending on such variables as slope, surficial geology, vegetation and infiltration.

As an objective of the project has always been to

> . . . devise and test a combination of techniques for determining the variety and character of mechanisms with which a culture . . . adapts its population distribution to other cultures . . . and to its environment (Gumerman and Johnson 1971:83)

it was necessary to carry out investigations in a region of

great natural diversity. As we note throughout this report, the test area is environmentally diverse. Earlier work had suggested that a possibility exists "that there is a tendency for increased variety and diversity at human community junctions as well as at plant and animal junctions" (Gumerman and Johnson 1971:84). Determining the presence and nature of these junctions became a major focus of the investigation.

The project team reasoned that a theoretical framework emphasizing the nature of adjustments that human cultures undergo in a given physical environment (cultural ecology) would be most applicable for the research. In a semi-arid to arid environment it was reasoned that one important set of adjustments would involve the management of available water for both domestic and subsistence activities. This in turn led to a concern with man-land and man-water relationships as well as man-man relationships, which culminated in the project interest in prehistoric land utilization and water management.

The Principal Investigator has always advocated the use of remote sensing technology in archaeology (cf. Gumerman and Lyons 1971). Biologists, hydrologists and geologists had been using remote sensing for some time, though seldom for a study concerned with man's past. It had been determined that all available low altitude and U-2 imagery would be utilized as aids both in planning ground truth activties and determining

the nature of the physical environment. The satellite imagery provided one missing element in the project. Until recently no orbital imagery showing the entire region encompassed by the test area had been available.

Because of the interdisciplinary nature of the project team, the generalized statement of goals which had evolved for the entire project was not mutually applicable to all disciplines. Therefore, specific goals and objectives were outlined for each specialist and specialty. In this way the various discipline specialists could gather data appropriate for answering questions designed to fit their specific interests, with the final integration of procured data occurring late in the project.

1.1 GOALS

The nature of the problem being investigated necessitated a specific statement of general goals applicable to all project team members. This process resulted in a triad of goals which were to be the ultimate focus of each member of the project team. These were as follows:

1) To define the environmental settings, both natural and cultural, of the test area;
2) To define and identify the adaptations made by the prehistoric and historic populations of the test area;

3) To identify the keys considered most useful for image interpretation in the use of high altitude imagery.

These goals were to be considered in light of the overall purpose of the project, the examination of prehistoric land use and water management systems.

Within the three major disciplines the following specific objectives were generated.

A. Hydrology-Geology

1. Identification and analysis of surficial geology in the test area.
2. Identification of available water resources.
3. How these were used by the prehistoric population.
4. Identification of any utilized canal systems.
5. Definition of geometric characteristics of selected small drainage basins.

B. Biology

1. Definition of the boundaries of the biological transition zone of the Central Arizona area.
2. Delineation of small vegetational communities and associated plant-water relationships.
3. Definition of biological sub-environments through the mapping of vegetation communities.

C. Archaeology

1. Determination of the types of primitive agriculture employed by pre-Columbian man in the test area.

2. Delineation and definition of the water resource management systems employed.

3. Determination of kinds of crops grown.

4. Determination of the number of acres under cultivation and irrigation.

5. Determination of the climatic conditions during the period of maximum occupation.

6. Location in time and space of the operators of the various land use and water management systems.

If the goals and objectives of the project present an idealized set of data to collect and interpret,a statement of task descriptions suggests the means by which these were to be satisfactorily accomplished. These tasks included the following:

1.2 TASKS

A) Visual interpretation of S190A photographs to delineate the boundary zone between the Upper Sonoran life zone and Lower Sonoran life zone, to map drainage basins within the

boundary zone, and to map major vegetation communities in north-central Arizona.

B) Utilization of S190B photographs, existing aerial photographs, existing topographic maps, limited aerial observation and reconnaissance field work to determine which physical properties of the ground surface are recorded by the S190 cameras and to determine which properties are the most useful in distinguishing between ecologically significant subareas within the test area.

C) Selection of representative drainage basins within the two life zones and the transition zone for detailed study. This study was to consider basin area, subdivisions, stream length, stream order number, slopes, bedrock type and rainfall distribution. Estimation of water available for each significant location within the basin was to be accomplished through use of the above parameters along with vegetation communities. Determination of the types of primitive agriculture and water resource management systems that were developed to utilize the resources of the different habitats was to be accomplished by field checking, visual observations from light aircraft, and the use of oblique aerial photographs.

D) Preparation of maps showing the distribution of drainage basin types, vegetation zones, major bedrock types, and the expected distribution of the different types of primitive

agriculture throughout the test site was to be based on the representative drainage basins and use of the S190A and S190B photographs. Map accuracy was to be checked by means of limited field work and observation of light aircraft.

1.3 PERSPECTIVE

To the archaeologist and natural scientist interested in the study of the development of our species, truth has literally lay on or under the ground. There has traditionally been no substitute for the ground truth survey. To a greater or lesser degree this axiom still holds and probably always will. An archaeologist, for example, must collect various kinds of samples, be they pollen, carbon 14, or an excavated sample of material from a site. This can only be accomplished through ground truth activities. The biologist, interested in the exploitation patterns in micro-environmental zones must construct detailed maps which sometimes include counting all members of all species within a zone, an activity that can only be accurate if ground truth information is gathered. Geologists and hydrologists face similar tasks -- again requiring observation of features at ground level.

There are numerous kinds of problems which can be investigated through ground truth activities. Generally speaking, it should be noted that a major, if not <u>the</u> major, reason

for conducting an archaeological survey is the analysis of location of sites and other cultural features. Some would stop here, others would go much further, suggesting that archaeologists ought to be using the collected data to test hypotheses concerning the cultural process which produced this data (F. Plog 1968). Exacting survey techniques and elaborate sampling strategies have been developed in archaeology (as well as in the more specifically environmental sciences) to provide information on various aspects of prehistoric (and historic) settlement systems and the relationships of these with the natural systems in which they are found. These research strategies, too numerous to detail here, have often had only two common points: 1) their diversity of goals and 2) the implicit assumption that information is to be collected through ground truth reconnaissance. Despite advances made in archaeological theory and method in recent years, the primacy of the ground based survey remains; modified, altered, elaborated upon or simplified. Yet the questions students of man's past are asking involve the necessity for the understanding of large regions, some so large as to make it impossible to collect a statistically valid sample by ground truth operations alone. Furthermore, project teams composed of a number of disciplines including archaeology are asking more wide-ranging questions than ever before. Many are the type addressed

elsewhere in this report.

These factors have lead to the attainment of more sopisticated answers to the questions being asked. It is no longer possible, for example, for an archaeologist to do a cursory or even intensive survey and then excavate a single site, or even three or four, which seem to be somehow "typical" of specific groups at a particular time. More often, archaeologists now examine a wide range of site types and other cultural features which represent <u>different</u> activities of the <u>same</u> culture, perhaps through examination of sub-environmental zones. Hypothetically, this might mean that habitation sites occur primarily on terraces above major water systems; defensive sites might occur in woodland areas or on difficult-access buttes, while small farming systems might occur along the floodplain where the practice of water control and diversion through irrigation is possible. In other words, these sites, which serve separate activities and behavioral complexes are representative of different aspects of the same cultural group, and their relationship one to another must be examined if the cultural system is to be understood.

Theoretically this approach is very promising, but it presents a number of difficult logistic, administrative and financial hurdles for the investigating team. A regional view need be adopted along with concomitant necessity of gathering

potentially useful data sets over many hundreds, if not thousands of square km. This requires that the project team not only know and understand the numerous variations in environment over a large region, they must also attempt to extrapolate the character of the prehistoric habitats from the presently occurring environmental situation. Quite obviously this type of investigation requires both more funding and more time than a project team has traditionally possessed. As suggested above, a partial solution to this problem is the rigor and parsimony one brings to the ground truth activity, through a statistical analytical approach which emphasizes the use of a randomized sampling strategy both in site discovery and excavation. Another partial solution is based on the increased utilization of remote sensing technology by project teams.

The perspective offered by various kinds of remote sensing instruments, from low altitude aerial photography to the orbital imagery provided by satellite, as opposed to that offered by ground truth survey, can be likened to the distance at which one views a painting. By standing very close, the viewer can discern elements of detail such as individual brush strokes and artistic technique. It is only when the viewer takes a few steps back that he can view the painting as a unified whole, as the artist intended. So it is with the study of man's relationship with his environment and with other

men. Paying attention <u>only</u> to the detail provided by ground truth reconnaissance may obscure and blur the systemic articulations to be found between natural and cultural parameters.

While remote sensing has assisted the student of man's past in many ways, there have been several areas of critical concern in which remote sensing technology has been of inestimable help. For the archaeologist these major categories include, 1) site discovery, 2) prediction of site locality, 3) reconstruction of past environments, 4) explanation of environmental adaptation, and 5) dating of cultural features.

Although the evolution of prehistoric archaeology and aerial photography was in many ways a parallel process, this remote sensing format was utilized only occasionally by archaeologists. Significant advances in remote sensing technology began occurring around 1960 at a time when the ways and means of studying man's past was also undergoing numerous changes, some of which have been mentioned above. The regional perspective and the interdisciplinary nature of many prehistoric investigations prescribed the use of this new technology where it could be applicable.

2.0 TEST AREA

The area selected for testing the applicability of satellite imagery in the analysis of prehistoric water management/land use systems is best characterized by one key concept: diversity. The area is diverse geographically, physiographically, biologically, and in prehistoric times, culturally. Much of this diversity can be noted in a casual motor trip through the area. Some is only seen from intensive ground truth investigations. At first glance one is struck by the topographic extremes. A casual observer would note that mountains, mesa tops, drainage basins, steep-walled canyons, broad alluvial floodplains and other topographic features all occur within a fairly short distance of one another. The systematic articulations between such features as these and the geology, hydrology, biology and prehistoric exploitation patterns are not readily apparent to the casual observer, yet there has never been any real doubt as to their existence. As has been previously noted one of our main objectives in this project has been to analyze and understand the nature and magnitude of these interrelationships.

2.1 ORIENTATION

The test area (Figure 2-1) lies in the south central portion of Arizona. It encompasses an area of approximately 4500 square kilometers. Geographic boundaries include Cordes Junction on the north, the Lake Pleasant-Calderwood Butte area on the south, the Bradshaw-Hieroglyphic Mountain complex on the west, and the Brooklyn Peaks and New River Mountains on the east. These boundaries include within them major portions of the Agua Fria and New River drainages.

This is rough terrain. The area is heavily dissected and includes within its boundaries gentle slopes, mesas, steep canyons, bajadas, plateaus and high peaks. Ground truth reconnaissance was conducted in three major physiographic sub-zones. These included the Mesa-Canyon complex in the northern portion of the test area, the transition zone in the central portion and the Basin and Range complex in the southern portion. The elevational difference between the highest and lowest points is approximately 4500 feet, ranging from 1250 feet in the desert flatlands near Calderwood Butte to approximately 5750 feet in the Bradshaws. Ground truth investigations were confined to elevations with an upper limit of 4000 feet. The region remains sparsely inhabited by human populations (except for the southern boundary where the metropolitan Phoenix area is steadily encroaching) and this factor in addition to

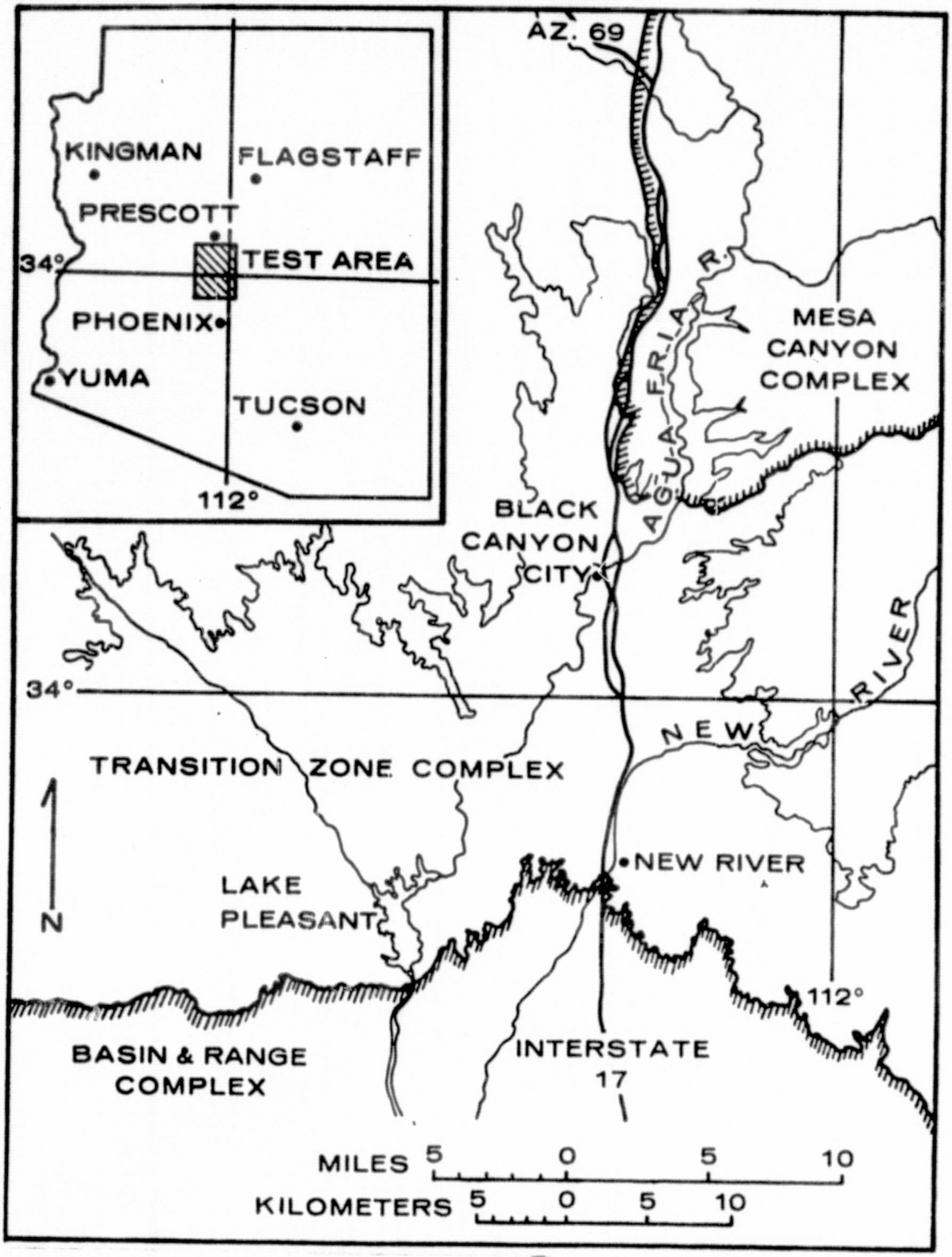

Figure 2-1. Test Area Orientation

the dual constraints of elevational extremes and dissected terrain made many areas of interest to the project virtually inaccessible (see Figure 2-1).

The study area extends from the Lower Sonoran Life Zone (consisting mainly of cactus-microphyll desert) in the south to the Upper Sonoran Life Zone in the north. A biological transition zone occurs as one travels from the desert floor to the plateau. In this transition zone the vegetation consists mainly of sahauro, octillo, many species of cacti, false palo verde, desert broom and banana yucca. Riparian communities are found in each of the biological zones where water necessary to support such communities is available. Throughout the test area are several species of plants which reach ecological and/or northern or southern geographical limits (Kearney and Peeble 1951). This has resulted in a "blending" of northern and southern species, such that the index of species diversity in the transition zone is greater than in either of the two bordering life zones. Ground truth activities were carried out in all three biological zones.

Prehistoric cultural boundaries and zones in the test area are much more obscure and therefore much more difficult to define than the natural and arbitrary boundaries so far described. Archaeological investigations suggested that a group (or groups) of people occupied and exploited the test area in

prehistoric times (which in this region lasts until the arrival of the Spanish in 1540). Their utilization of this area is most pronounced between ca. AD 1100-1450, and appears to have been the most intensive use of the area until the present day. Despite this it is only with much uncertainty that we can say who these people were. Suffice it to say here that during our investigations we were much more concerned with questions relating to the activities of these people, particularly with regards to their exploitative activities and their relationships to an intricate environmental situation, than we were with questions of identity, with one exception. Insofar as these exploitative activities and the man-land-water relationships which provided their natural parameters corresponded to definable natural boundaries, questions of identity were of interest. Even in this instance, however, the attachment of a name to these groups was of less importance than was the understanding of the relationships which formed both cultural and natural systemic interrelationships.

2.2 REMOTE SENSING DATA

Skylab EREP Project 9670 and the "Hydrology of Prehistoric Farming Systems in a Central Arizona Ecotone" used a variety of remote sensing data in an effort to attain its goals. These included Skylab imagery supplied by NASA, U-2

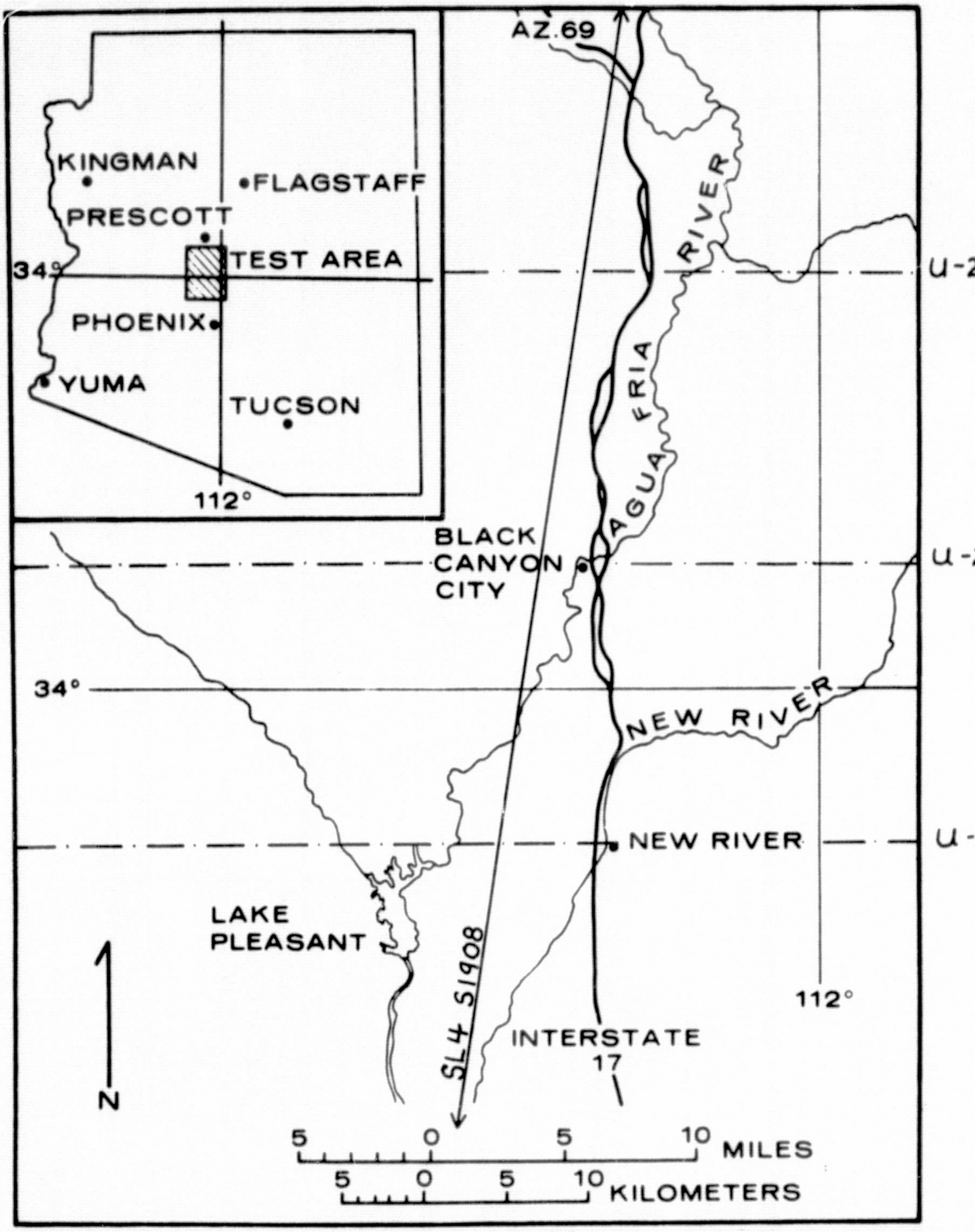

Figure 2-2, 2-3. Index Map of EREP and Aircraft Coverage

overflights, and low-level aerial photography supplied by the U.S. Geological Survey.

The Principal Investigator had concluded that the S190 and S192 formats would have the greatest practical applicability for use on this project. These formats had been selected for use by the investigator for a number of reasons. The Principal Investigator had earlier noted that:

> For the last several years various remote sensing techniques such as false color infrared (IR) aerial photography and infrared imagery have been utilized as detection techniques in archaeology with great success (Gumerman and Johnson 1971:85).

This suggested use of both the S190 and S192 formats, as did the knowledge of these two EREP sensors appeared to have the most immediate application to geologic investigations.

A brief review of the material we received for our interpretations follows some preliminary remarks on the imagery.

We felt that the best possibility for data retrieval would be accomplished with imagery from all three manned missions. Not only would we have samples taken at three different times of the year but also more than likely at three different times of day.

We felt that coverage taken over the course of the year would be most useful for the biologists on the project team, as it would provide a comparative data base which illustrated vegetational changes as various plant species completed a cycle.

The time of year that coverage was made was less crucial but also important to geologists-hydrologists and archaeologists. For these project team members, who were dealing with an essentially unchanging set of variables, the variation in pictures with respect to time of day seemed of greater importance. Cultural features, difficult to see from an orbital distance of 235 miles away, can be obscured easily by shadows. This is also true for some of the small drainage networks (though admittedly less so), as well as some bedrock types and hillside vegetation.

Conditions beyond anyone's control prohibited this accomplishment. Clouds (over central Arizona) heavily obscured the first manned mission in all formats. Imagery received from SL3 taken during the fruiting months of September and October was of little utility for our work, as the coverage only included the southwestern corner of our test area. Fortunately, the imagery received from the third manned mission was generally excellent. The only drawback was that this coverage had been taken in early January, during a season when neither flowering nor fruiting in various plant communities was occurring.

2.2.1 Skylab

The following data was requested:

A) The Multispectral Photographic Camera (S190A)

We received imagery from all three missions. Because of the need on our project of high resolution and thereby high interpretable content we requested the following S190A materials from all three missions:

1) Aerochrome IR color, type EK2443, bandwidth .5 to .88 m, filter EE.
2) Aerial color (high resolution) type SO-356, bandwidth .4 to .7 m, filter FF.
3) IR aerographic B&W, type EK2424, bandwidth .7 to .8 m and .8 to .9 m, filters CC and DD.
4) Pan-X aerial B&W, type SO-22, bandwidth .6 to .7 m and .5 to .6 m, filters BB and AA.

B) Earth Terrain Camera (S190B)

The following materials were to be interpreted:

1) Aerial color, high resolution, type SO-242, wavelength .4 to .7 m, no filter.
2) Aerochrome IR, color, type EK 3443, wavelength .5 to .88 m, filter W-12.

It should be noted here that the S190B coverage of Arizona was completely lost during Skylab 2. However, the S190B imagery from Skylab 4, particularly 1) above was of excellent quality and proved to be the most useful set of imagery

received, although the southern boundary of the test area was not covered.

C) Multispectral Scanner (S192)

The following materials were requested:

1) Bands 5 and 6, coverage .62 to .67 m and .68 to .76 m.*

2) Bands 12 and 13, coverage 2.10 to 2.35 m and 10.20 and 12.5 m.**

3) Bands 12 and 13, computer compatible tapes.***

Two explanatory notes are germane here. Although the project had originally requested bands 5 and 6, they were found unsuited to our needs and bands 12 and 13, which appeared more suited, were substituted for Skylab 3 and 4. Unfortunately, the principal investigator and project team had no access to instruments of enhancement for this format. Computer compatible tapes of the Skylab 4 mission have been submitted for enhancement to the USGS, but no results have yet been forthcoming. We noted that without attempts to eliminate noise, the resolution the pictorial quality were not up to our necessary requirements in terms of ground truth. As the manipulations for noise elimination could not be carried out, we were unable to utilize, analyze or interpret this format with regards to our

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*Skylab 2 only.
**Skylab 3 and Skylab 4.
***Skylab 4 only.

project requirements.

In summary, it must be emphasized that the results of our investigations in terms of imagery utility and applicability is necessarily based on less than a complete set of satellite data. Our analyses, especially as regards imagery interpretation are restricted to Skylab 4 and the S190 formats.

2.2.2. Aircraft

For comparative purposes we utilized lower altitude imagery which was available to us. These formats (all in black and white) included:

D) U-2 overflights -- material was received of U-2 aerial photography which had been taken for purposes of rechecking topography in the state for mapping purposes. This coverage encompassed our entire test area. The following data were utilized:

1) Lower Sonoran Zone: date, Aug. 22, 1972; altitude, 65,000 ft. above mean sea level; camera, RC-10; film Plus X 2402; Flight 72-143; Roll 00647; Frames 4922-2938; From whom available, EROS Data Center, Sioux Falls.

2) Transition Zone: date, Nov. 9, 1972; altitude, camera, film, same as above; flight 72-195; Roll 00807; Frames 7578-7585.

TABLE 2-I

EREP DATA RECEIVED

Date	Sensor	Mission	Roll	Frames	Medium	Comments
June 1973	S190A	SL-2	04	195-202	High-resolution color	Grainy above 7x
Sept. 1973	S190A	SL-2	04	195-202	High-resolution color	
Sept. 1973	S190A	SL-2	03	195-202	Color infrared	
June 3, 1973	S192	SL-2			Screening film	
Sept. 12, 1973	S192	SL-2	Orbit 3 Run 6			
Sept. 1973	S190A	SL-3	33	241-252	Color infrared	
Sept. 1973	S190A	SL-3	27	057-065	Color infrared	
Sept. 1973	S190A	SL-3	34	241-252	High-resolution color	
Sept. 1973	S190A	SL-3	28	057-066	High-resolution color	
Sept. 1973	S190A	SL-3	36	241-251	B/W	
Sept. 1973	S190A	SL-3	30	059-064	B/W	
Sept. 1973	S190A	SL-3	35	241-250	B/W	
Sept. 1973	S190A	SL-3	29	059-064	B/W	
Sept. 1973	S190A	SL-3	31	241-250	B/W infrared	

TABLE 2-I -- Continued

Date	Sensor	Mission	Roll	Frames	Medium	Comments
Sept. 1973	S190A	SL-3	34	241-250	High-resolution color	
Sept. 1973	S190A	SL-3	32	241-250	B/W infrared	
Sept. 1973	S190A	SL-3	36	241-250	B/W	
Sept. 1973	S190A	SL-3	33	241-250	Color infrared	
Sept. 1973	S190A	SL-3	35	241-250	B/W	
Sept. 1973	S190A	SL-3	27	059-064	Color infrared	
Sept. 1973	S190A	SL-3	28	059-064	High-resolution color	
Sept. 1973	S190A	SL-3	30	059-064	B/W	
Sept. 1973	S190A	SL-3	29	059-064	B/W	
Sept. 1973	S190A	SL-3	26	059-064	B/W infrared	
Sept. 1973	S190A	SL-3	25	059-064	B/W infrared	
Sept. 1973	S190B*	SL-3	86	007-025	High-resolution color	
Feb. 1974	S190A	SL-4	71	092-121	B/W	
Feb. 1974	S190A	SL-4	1B	020-056	B/W infrared	
Feb. 1974	S190A	SL-4	67	098-114	B/W infrared	

TABLE 2-I -- Continued

Date	Sensor	Mission	Roll	Frames	Medium	Comments
Feb. 1974	S190A	SL-4	68	092-119	B/W infrared	
Feb. 1974	S190A	SL-4	72	103-113	B/W	Very dark, grainy
Feb. 1974	S190A	SL-4	2B	020-059	B/W infrared	
Feb. 1974	S190A	SL-4	68	093-116	B/W infrared	
Feb. 1974	S190A	SL-4	69	104-112	Color infrared	
Feb. 1974	S190A	SL-4	6B	020-056	B/W	
Feb. 1974	S190A	SL-4	1B	029-047	B/W infrared	
Feb. 1974	S190A	SL-4	2B	029-058	B/W infrared	Much too dark, grainy above 7x
Feb. 1974	S190A	SL-4	5B	030-048	B/W	
Feb. 1974	S190A	SL-4	6B	029-048	B/W	
Feb. 1974	S190A	SL-4	3B	030-041	Color infrared	Too dark
Feb. 1974	S190A	SL-4	4B	030-041	High-resolution color	Too dark
Feb. 1974	S190A	SL-4	69	104-112	Color infrared	
Feb. 1974	S190A	SL-4	70	100-112	High-resolution color	
Feb. 1974	S190A	SL-4	4B	034-037	High-resolution color	

TABLE 2-I -- Continued

Date	Sensor	Mission	Roll	Frames	Medium	Comments
Feb. 1974	S190A	SL-4	6B	034-038	B/W	
Feb. 1974	S190A	SL-4	5B	034-038	B/W	
Feb. 1974	S190B	SL-4	90	301-313	High-resolution color	Excellent, even with high magnification
Feb. 1974	S190B	SL-4	94	226-238	High-resolution color	
Feb. 1974	S190B	SL-4	93	59-70	Infrared color	
	S192	SL-4	pass 83		Screening film	
	S192	SL-4	pass 60		Screening film	
Feb. 1974	S192	SL-4	pass 83		Screening film	
Nov. 14, 1974	S192	SL-4	orbit 60 Run 12		Sensor data	

*No S190B SL-2 coverage; SLS190B missed test area completely.

Figure 2-4. S190A Aerial Color Infrared Image of Test Site Roll: 3B Frame: 036 Date: Feb. '74

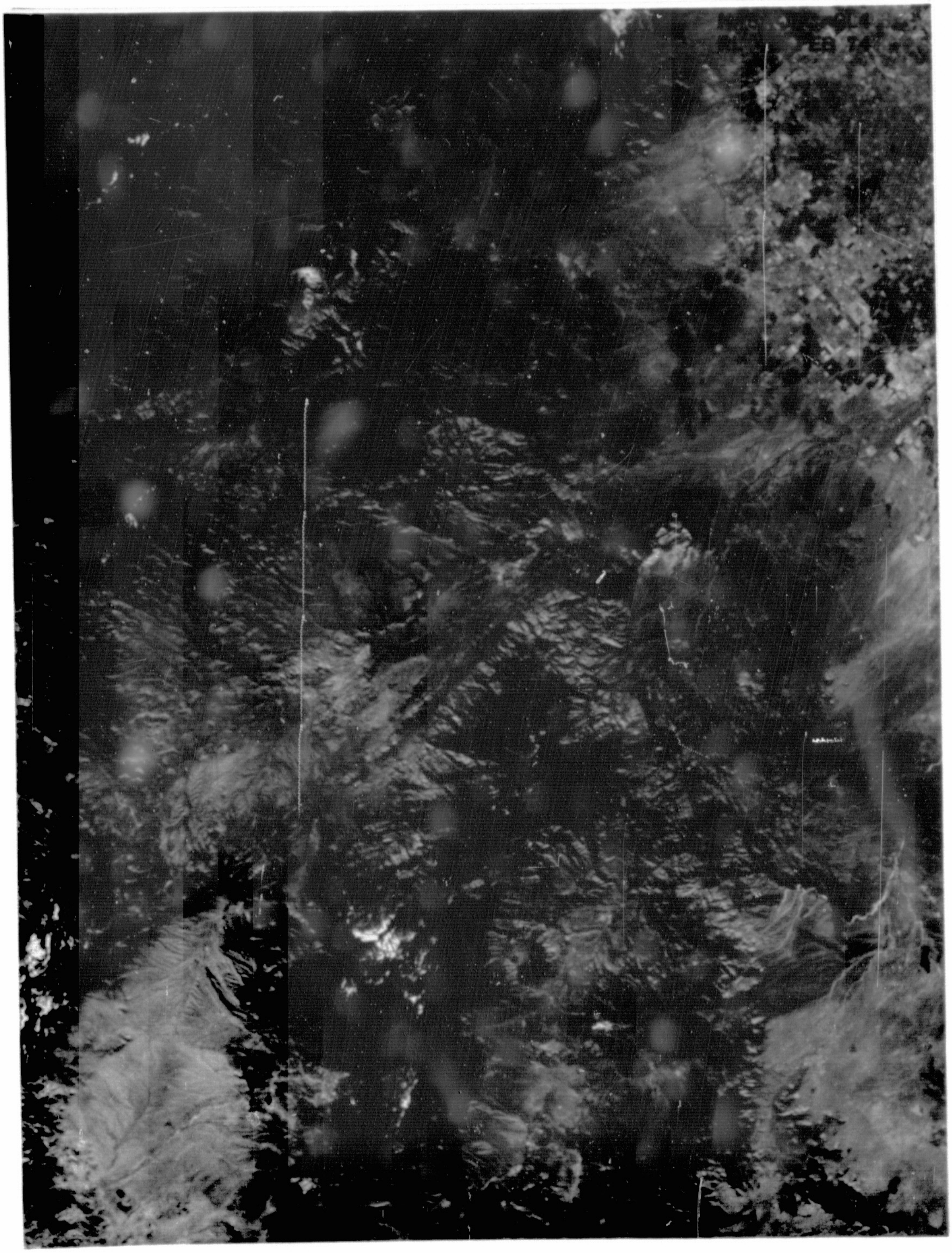


Figure 2-5. S190A Aerial Color Image of Test Site
Roll: 4B Frame: 036 Date: Feb. '74

3) Upper Sonoran Zone: date, June 20, 1973; altitude, camera, film, same as above; Flight 73-098; Roll 01268; Frames 2655-2662.

E) Low level aerial photography -- this material was taken during the springs of 1970, 1972 and 1975. The 1970 and 1972 coverage was taken during surveys of portions of the test area by the Prescott College Archaeological Survey under the direction of the Principal Investigator. The 1975 coverage included small portions of the transition zone and was originally accomplished for use in mapping certain major archaeological sites. The following data were utilized:

Date:	Altitude:	Camera:	Aircraft:	Film:
70-71	900-2,000 ft.	70mm.	Cessna 310	Panchromatic
70-72	2,500-4,000 ft.	9 x 9	de Haviland Beaver	Panchromatic

Photographs available through the Central Arizona Ecotone Project, Southern Illinois University.

It should be noted that our original intention was to fly special low-aerial overflights of the test area to engender data which could be compared to the coverage NASA was providing. This necessity was effectively nullified when the U-2 and other lower level imagery became available to us.

Figure 2-6. Black and White U-2 Image of a Portion of the Test Site.

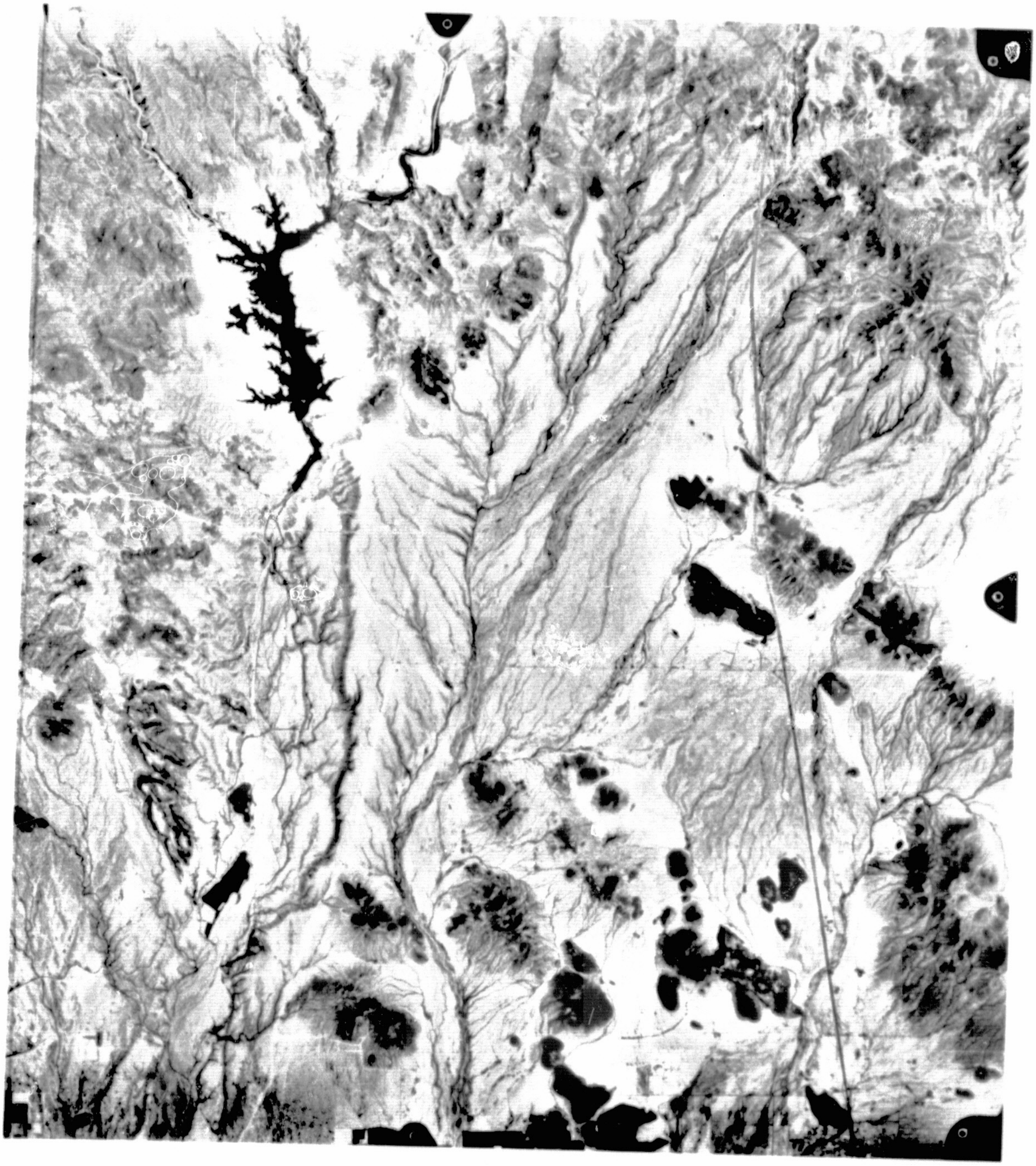
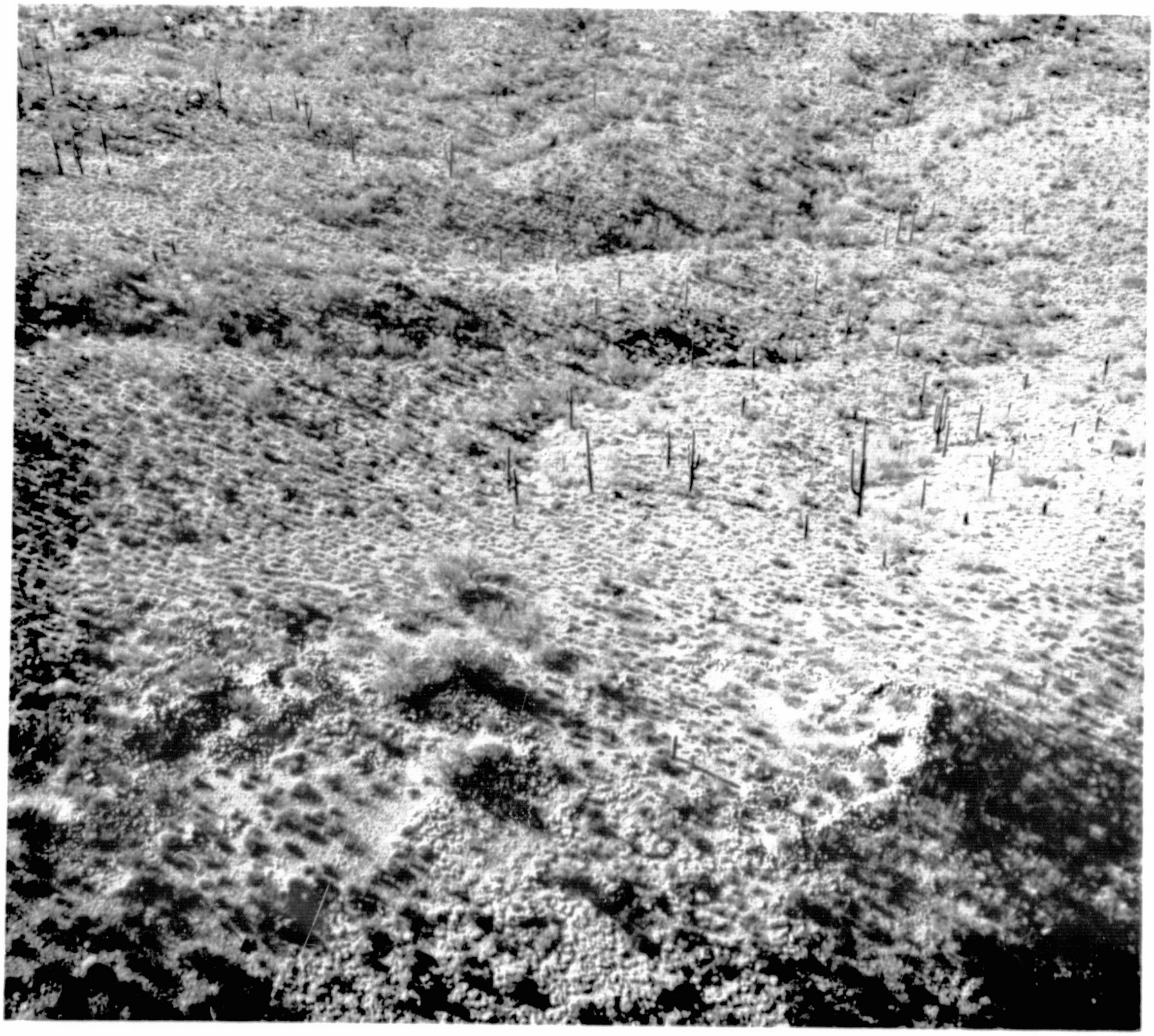


Figure 2-7. Black and White Low Level Image of a Portion of the Test Site.



2.3 FIELD SURVEY

The sheer size and enormous diversity of the test area made planning for ground truth reconnaissance a difficult task. It was clear from the outset that we could not hope to cover on foot even one-tenth of the entire test area.

This area of central Arizona had been the scene of only very limited archaeological survey(*cf. Dittert, Fish and Simmonis 1969; Grady 1973; Kemrer, Schultz and Dodge 1972), and had certainly never been the object of an ongoing inter-disciplinary research project. The project team was interested in ascertaining data to test hypotheses regarding the inter-dependence of the natural and social environments of pre-Columbian man. Our need was to analyze in detail man-water-land relationships, and to do so ground truth activities had to be conducted primarily in and near drainage basins. Additionally, it was necessary to examine drainage nets with different kinds of geometric characteristics. These considerations were cross-cut by the need to carry out our investigations in the Upper and Lower Sonoran life zones and the transitional zone in between.

Archaeologists and biologists concentrated their ground truth efforts in each of the three zones, as did the hydrologists on the project team. The hydrologists, however, studied some additional drainage nets identified from the imagery. These

included networks in the Hieroglyphic Mountains (Padelford Wash), washes on the northern shore of Lake Pleasant, washes on the eastern side of the lake, and Soap Creek (also investigated by archaeologists) in the foothills of the Bradshaw Mountains.

Our original strategy called for carrying out our ground truth activities after having examined the satellite coverage. We felt that this procedure would better enable us to interpret the applicability of the imagery to investigations of the nature we were undertaking. As we received our imagery data sets (including SL2) at a later date than we had anticipated, much of our ground truth data for scientific controls was of necessity collected prior to our reception of Skylab imagery.

Each member discipline of the project team carried out their own particular ground truth activities. As each discipline was collecting somewhat different information, a brief statement regarding each seems in order.

Biology -- Biologists on the project team were most concerned with defining the boundaries of major environmental and sub-environmental zones. They mapped major vegetation communities working on both a macro and micro environmental scale. To this end biologists assembled a plant list of species noted in each of the three major biological zones. They further mapped the major vegetation within the selected basins as

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well as in the non-riparian communities in the general area of a given basin.

Hydrology -- The hydrologists on the project team carried out ground truth activities in 17 separate drainage basins. One of their major tasks included an attempt to determine the water available to human populations for both domestic and agricultural needs. As a means of making these determination the width and average depth of the various wash channels was measured in three areas close enough to one another to determine such an average. Additionally, the hydrologists noted the general nature of the wash bottom. Of particular interest was the distinction between a bed-rock bottom and one which was characterized by the presence of alluvium.

Archaeology -- The low altitude and ground truth surveys carried out during the springs of 1970 and 1972 had provided some data on site type, location and distribution. Nonetheless the study area was virtually unknown archaeologically.

Survey was conducted in selected basins in the Upper Sonoran, transition zone and Lower Sonoran subsections as well as in approximately one kilometer areas from these basins, which were for the most part, secondary drainage networks. These activities were augmented by additional survey in the spring of 1975. This additional activity differed from the

original in that emphasis was on localities not primarily associated with major drainages.

3.0 DISCIPLINE STUDY RESULTS

The objective of the individual discipline studies is to provide a basis for the total project synthesis. Each discipline is assigned specific goals the conclusions of which will provide a data base for the answers to questions raised by the over-all project tasks. The discipline goals are designed to overlap each other, and in doing so the project achieves an multi-disciplinary approach to problem solving. For example, data collected by the hydrologists as to drainage basin geometry supplies the archaeologists with information regarding probable agricultural localities. The following discipline sections examine in detail the results of the various studies, and describe to a limited extent the inter-disciplinary approach utilized by the project.

3.1 GEOLOGY

The accompanying photogeologic map, Figure 3-1, represents identification of surficial bedrock types in the CAEP study area. It was compiled using both Skylab imagery (SL4, S190A and S190B) and conventional aerial photographic interpretation techniques. Compilation of the map was completed by Dr. Thor Karlstrom of the USGS office in Flagstaff. Although other comittments prevented Dr. Karlstrom from submitting a written report on this work, he discussed the procedures and evaluation of the imagery with other members of the project team. The following discussion reflects these.

Utilizing only Skylab photography approximately 90% of the boundary lines between bedrock types could be identified. The most useful format in making such identifications was the high resolution color from the Earth Terrain Camera (S190B). It should be noted that T. Karlstrom worked with imagery from both SL3 and SL4.

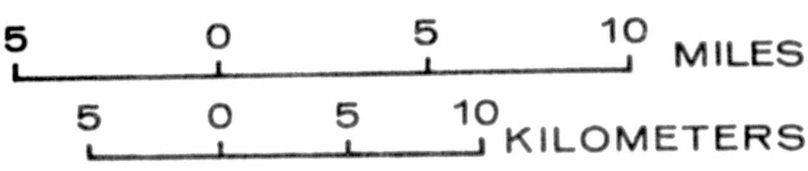
As no means was available for enhancement of multispectral scanner imagery, this technique was not utilized in this analysis. Karlstrom has utilized scanning data on other occasions and believes that manipulation of scanner data could enable the investigator to more clearly delimit geological

TABLE 3-I

LEGEND FOR ENVIRONMENTAL GEOLOGY MAP

EXPLANATION:

F	FLOODPLAINS AND LOW TERRACES
A3	INTERMEDIATE TERRACES
A2	OLDER TERRACES AND ALLUVIAL FANS
A1	FOLDED GRAVELS
Va	FAULTED VOLCANIC ROCKS; BASALTIC FLOWS, TUFFS, AND INTERBEDDED ALLUVIUM ; INCLUDES OBSIDIAN USED BY PREHISTORIC CULTURES
G	GRANITIC AND OTHER CRYSTALLINE ROCKS; LOCALLY INCLUDES RED RHYOLITE
M	METAMORPHIC ROCKS; INCLUDING SCHIST, GNEISS, AND LOCALLY GREENSTONE



COMPILED BY THOR KARLSTROM
U.S. GEOLOGICAL SURVEY
1975
FROM SKYLAB AND CONVENTIONAL PHOTOGRAPHY

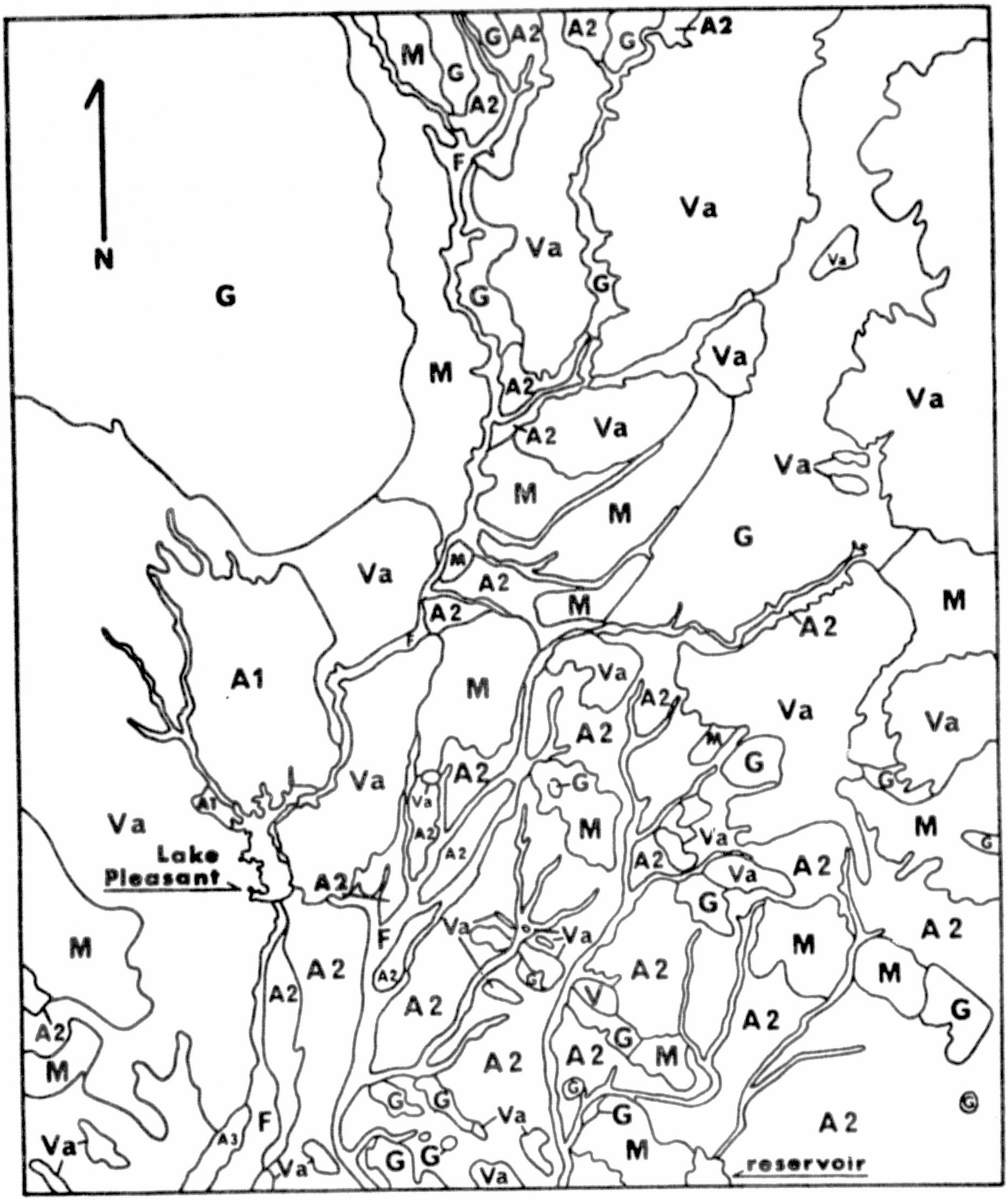


Figure 3-1. PHOTOGEOLOGIC SKETCH MAP OF THE TEST AREA SHOWING THE MAIN ROCK TYPES. NOTE THE AREA SHOWN IN THIS MAP IS ESSENTIALLY THE SAME AS SHOWN IN FIGURE 1.

boundaries than do any of the other conventional photographic formats.

Karlstrom further suggested that in his opinion the time of day at which imagery was taken could be seen as a critical factor in identifying geologic materials. Most preferable would be imagery taken sequentially both early and late in the day. Subtle distinctions, particularly tonal variations, caused by differential heat retention and reflectivity would become much more noticeable in imagery taken sequentially during the day. The diachronic attribute of repeated photography is to be emphasized, with regards to surficial geology. There can be seasonal differences in surficial deposits. For example, in an area of rainy and dry seasons, unconsolidated deposits after a rainfall provide conditions not evident on imagery prior to the rain. The same is true for vegetation.

T. Karlstrom noted that there were several drawbacks on the use of only satellite imagery for construction of a map such as in Figure 3-1. Most difficult to reconcile is the problem of resolution. Even the resolution capabilities of the Earth Terrain Camera did not assist in delimiting boundaries between finer geological structures. Nor could this problem be solved by enlarging the imagery or increasing magnification. In this regard conventional aerial photography,

in particular U-2 imagery allows for much greater resolution. Undegraded U-2 imagery is probably the best technique currently available for photographic mapping, although often only degraded film is available for civilian use. In some boundary situations, however, Dr. Karlstrom noted that there were advantages to the use of Skylab imagery over conventional photography. The specific situations referred to by this statement were not clarified. It is important to note that in this regard given the seemingly unresolvable technical problem of finer resolution on the satellite imagery, Dr. Karlstrom was impressed by the synoptic nature of this imagery. The wide expanse of terrain covered in successive pairs of frames is most helpful in noting general trends of surficial geology, trends that could not be as easily delineated or understood when using the relatively restricted range of the earth's surface provided by U-2 coverage and the narrowly restrictive range offered by low altitude imagery.

In summary, Karlstrom noted two positive aspects of the use of satellite imagery in the determination of surficial geological boundaries:

1) That in all probability if other kinds of data were not available (this would include data from other imagery formats, existing geological maps, and ground truth) a great deal of information can be

derived by the investigation from Skylab only.

2) An expert photogeologist would have little difficulty in delineating boundaries between bedrock types or even subdividing geological beds through analysis of Skylab imagery.

A comparison of "ground truth" in selected areas with Karlstrom's map shows, in general, good agreement. There are several areas in which the ground truth disagrees.

1) Daisy Mts. Quad -- in the area (area #3 on map) around Ariz. T:4:8 -- mapped as A_2 (older terraces and alluvial fans) -- this is reasonable, however, metamorphic rocks crop out in the washes; the alluvium is a relatively thin veneer.

The portion of the area mapped as M (metamorphic) is said to be all metamorphic, but it certainly does include volcanic rocks also.

2) The area north of Lake Pleasant is mapped as A_1 (folded gravels).

This area had been selected for study because it looked (from U-2 photos) like badlands topography, i.e.greatly dissected sediments; it is really a veneer of gravels over volcaniclastic rocks.

3) There is an extensive area underlain by well-bedded sedimentary rocks, around and south of Rock Springs along I-17.

As there are no references to such a formation on the photogeologic sketch map, there seems to be some problem here. The entire area is mapped as M (metamorphic rock).

3.2 HYDROLOGY

The hydrology studies were designed to determine the existing available water resources and the characteristics of the hydrological networks of the test area. Additionally, a test to determine run-off amounts from stream channel data (Hedman 1970) was conducted in selected drainage basins. Twenty drainage basins were examined in detail using both photographic resources and ground truth studies. The criteria for basin selection is discussed below. The various drainage basin types were also examined by the biologists and archaeologists on the project.

3.2.1 Drainage Basin Analysis

The drainage basins studied in detail in the Central Arizona area were selected using several criteria. Those basins in which archaeological sites were known to exist, as well as those in which an archaeological reconnaissance either had been completed or was contemplated were the first basins chosen for detailed examination. Additional basins, not specifically related to archaeological investigations, were selected by the

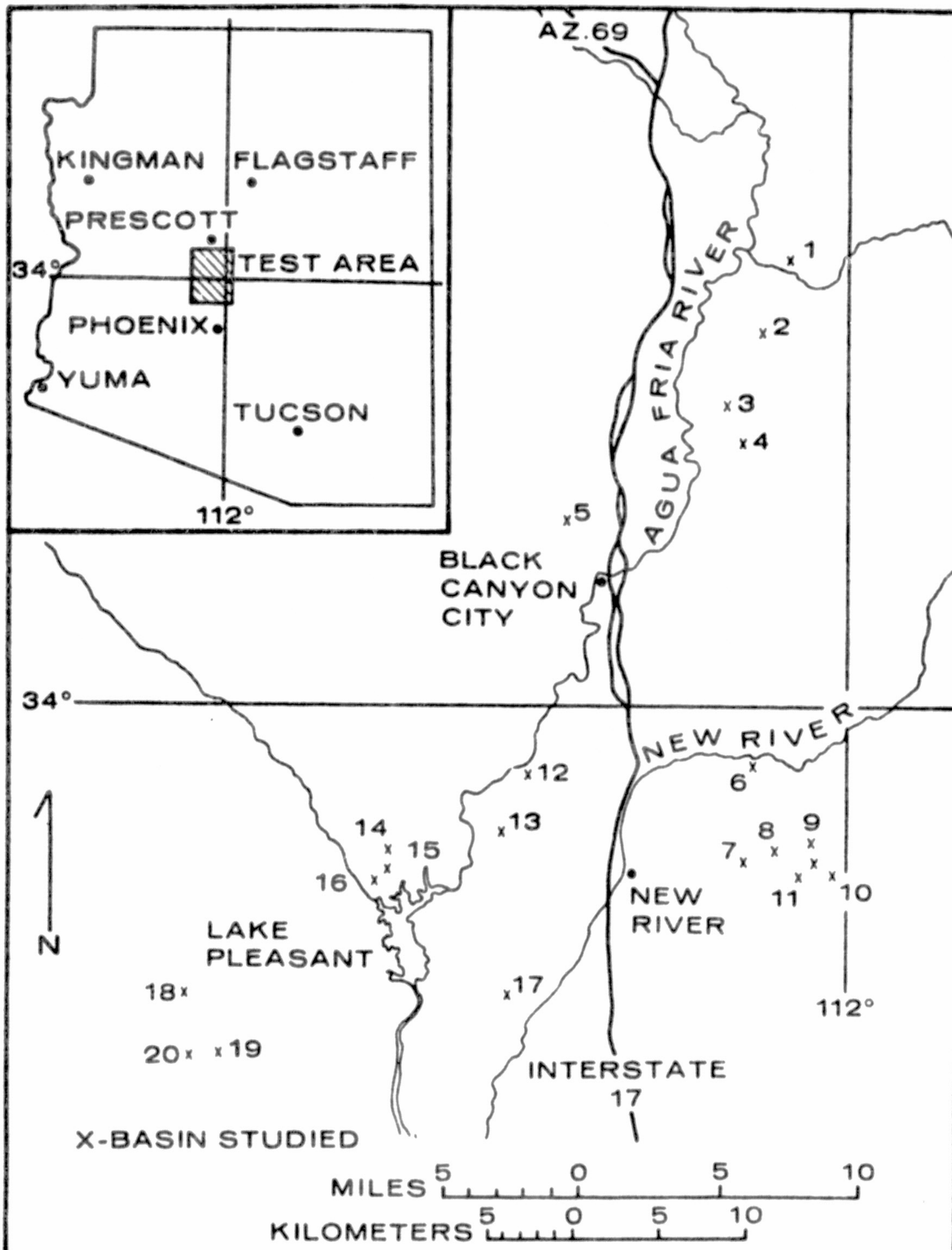


Figure 3-2. MAP SHOWING LOCATION OF THE TEST AREA (AND DRAINAGE BASINS STUDIED IN DETAIL)

TABLE 3-II

IDENTIFICATION OF DRAINAGE BASINS

Names in parentheses refer to informal names used for basins during the field work. The location given is for the mouth of the drainage basin; it may or may not coincide with the mouth of the drainage relative to a higher order stream.

Number	Location
Joes Hill 7½ minute quadrangle	
1.	Bishop Creek (Baby Canyon) SE¼ SW¼ Sec. 17, T.10N, R.3E.
2.	Tank Creek (Perry Tank Canyon) SE¼ NE¼ Sec. 36, T.10N., R.2E.
3.	Lousy Canyon NW¼ SW¼ Sec. 6, T.9N., R.3E.
4.	Larry Creek (Larry Canyon) NW¼ NW¼ Sec. 18, T.9N., R.3E.
Black Canyon City 7½ minute quadrangle	
5.	Soap Creek SE¼ NE¼ Sec. 28, T.9N., R.2E.
Daisy Mountain 7½ minute quadrangle	
6.	Unnamed wash NW¼ NE¼ NW¼ Sec. 9, T.7N., R.3E.
7.	Unnamed wash (Daisy Mountain A) NW¼ NW¼ Sec. 33, T.7N., R.3E.
8.	Unnamed wash (Daisy Mountain B) SE¼ SW¼ Sec. 33, T.7N, R.3E.
9.	Unnamed wash (Daisy Mountain C) NE¼ NW¼ Sec. 34, T.7N., R.3E.
10.	Cline Creek (Daisy Mountain D) NW¼ NW¼ Sec. 3, T.6N., R.3E.

TABLE 3-II -- Continued

Number	Location	Location

11. Unnamed wash (Daisy Mountain E)
    above jeep trail crossing, NW¼ SW¼ Sec. 34, T.7N., R.3E.

New River 7½ minute quadrangle:

12. Unnamed wash (Wild Burro Mesa - North Basin)
    NW¼ NW¼ Sec. 7, T.7N, R.2E.

13. Unnamed wash (Wild Burro Mesa - South Basin)
    NE¼ SE¼ Sec. 26, T.7N., R.1E.

Governor's Peak 7½ minute quadrangle:

14. Coles Wash
    NW¼ SE¼ Sec. 29, T.7N., R.1E.

15. Unnamed wash southwest of #14
    NE¼ NW¼ Sec. 32, T.7N., R.1E.

16. Unnamed wash southwest of #15
    NW¼ SW¼ Sec. 32, T.7N., R.1E.

Biscuit Flat 7½ minute quadrangle:

17. Unnamed wash (Sweat Canyon)
    at triangulation station, elevation 1622
    NE¼ SE¼ Sec. 35, T.6N., R.1E.

Hieroglyphic Mountains SW 7½ minute quadrangle:

18. Unnamed wash (Padelford Wash - North Basin)
    NE¼ NE¼ Sec. 36, T.6N., R.2W.

19. Padelford Wash (Padelford Wash - South Basin)
    SW¼ SW¼ Sec. 31, T.6N., R.1W.

20. Padelford Wash (Padelford Wash - North plus South Basin)
    NE¼ NE¼ Sec. 1, T.5N., R.2W.

Daisy Mountain 7½ minute quadrangle:

21. Cline Creek (Daisy Mountain C - D - E)
    NE¼ NE¼ NW¼ Sec. 4, T.6N., R.3E.

investigator following examination of U-2 aerial photography. The total sample provided basins with a wide range of areas, a variety of drainage network patterns including dendritic, trellis, and parallel networks, and an overall sample that adequately represented portions of the Upper Sonoran to Lower Sonoran range of the test area.

Certain of the basins selected on grounds other than archaeological were subsequently examined by the archaeologists to determine what, if any, use had been made of those areas by the prehistoric inhabitants of the region.

The locations of the basins examined are shown on Figure 3-2. A more precise location for each basin is given in Table 3-II.

Analysis of each drainage basin involved both laboratory and field work, and generally assumed the following pattern.

<u>Laboratory Work</u>

1) On U.S. Geological Survey topographic maps (7½ minute quadrangles, scale 1:24,000) the drainage divide for the basin was determined and drawn on the map.

2) Overlays of each drainage basin were prepared showing the drainage divide and the drainage network. Both perennial and intermittent or ephemeral elements of the network, as shown by the appropriate blue symbols, were included, but

no interpretive extending of this network on the basis of topography was done, even where it would have been easy to do so. Streams of the network were assigned a stream order number according to the system of Strahler (1957), in which "finger-tip" elements of the network lacking tributaries are first-order streams, two first-order streams form a second, two seconds a third, and so on.

3) From the overlays and their respective maps the following measurements or calculations were made:

<u>Bifurcation ratios</u> -- The number of streams of each order was determined and the ratio of the number of streams in one order to the number of those in the next higher order was calculated to give the bifurcation ratio (as described by Horton, 1945). Mean bifurcation ratios were calculated for each basin.

<u>Drainage basin area</u> -- The area of the basin was determined by using a polar planimeter.

<u>Length of streams</u> -- The length of each stream was determined using a map measurer; the total length of the network was calculated.

<u>Drainage density</u> -- The drainage density, or the ratio of the total length of the drainage network to the area

of the basin (drainage density $= \frac{\Sigma L}{A}$, Horton 1945), was calculated.

Relief ratio -- The relief ratio, or the ratio of the difference in elevation within the basin to the length of the basin, as determined along a line essentially parallel to the main drainage line (Schumm 1956:612), was determined.

Field Work

Most of the emphasis in initial field examinations of the drainage basins was given to attempting to determine the mean annual runoff for the basin. None of the principal streams draining the basins analyzed are gauged, therefore the approach outlined and utilized by Hedman (1970) was employed. This approach, which is useful for examining ungauged intermittent or ephemeral streams in arid and semi-arid regions, provides estimates of mean annual runoff based on the width and average depth of stream channels.

The field procedure utilized was essentially that outlined by Hedman (1970), and consisted of the following steps:

1) At the mouth of the basin, at least three sites were located where the necessary measurements could be made (Note: three locations were preferred; in some channels this was not possible).

The width and average depth at each location were determined, utilizing as relevant indicators of channel width and depth point bars, island bars, and/or berms, and the lower limit of permanent vegetation (for a more complete description of these features and the rationale employed for using them, the reader is referred to Leopold and Wolman 1957; and Hedman 1970; E5 - E10, respectively).

3) Using a graphical form of the relationship between width, average depth, and mean annual runoff (Figure 9 of Hedman 1970; E14, and more detailed versions thereof), the mean annual runoff for each set of readings would be determined. If a wide discrepancy existed among the three approximations at a given site, additional measurements would be made and apparently spurious values discarded if sufficient reason for doing so existed.

The data obtained subsequently were used to calculate the runoff values more precisely, according to the following equation given by Hedman (1970:E13):

$$Q_e = 258\ W^{0.80}\ D^{0.60}$$

where Q_e is mean annual runoff in acre-feet per year, W is the width in feet, and D is the average depth in feet. The three sets of data for each basin were calculated; the runoff values listed for each basin (Table 3-III) are mean values derived from, typically, those three sets of data.

4) Qualitative observations were made on the general geologic setting of the wash, the nature of the streambed materials, and any other relevant factors.

Results of Drainage Basin Analysis

General

Twenty-one basins constitute the sample in this study. They range in area from .294 square miles (Basin 6) to 45.63 square miles (Basin 1). The mean area of all is 7.69 square miles. Elevations of the mouths of the basins range from 1567 feet above sea level, in the south (Basins 14, 15, and 16), to 3200 feet in the north (Basin 1). The highest elevation within any of the basins is 6814 feet above sea level (Pine Mountain, Basin 1). Dendritic drainage networks predominate; however, the fundamental patterns of several basins or combinations of basins include both trellis and parallel patterns. Eleven of the twenty-one basins studied show evidence of habitation by prehistoric peoples.

Table 3-III summarizes the data from all the basins. Selected characteristics are discussed more fully below.

Geometry of Drainage Networks

As noted above, dendritic drainage patterns predominate, both in terms of overall pattern and in terms of patterns

TABLE 3-III

DATA SUMMARY OF DRAINAGE BASINS

Basin	Area, in Square Miles	Elevation - Highest Point and Mouth	Relief Ratio	D-dendritic, T-trellis, P-parallel First Given is Dominant	Order of Master Stream	Bifurcation Ratio	Drainage Density	Mean Annual Runoff, in Acre-Feet per Year	Mean Annual Runoff per Square Mile (= unit runoff), in Acre-Feet per Square Mile per Year	Estimated Mean Annual Precipitation in Inches Per Year	Estimated Mean Annual Precipitation, in Acre-Feet Per Year	Runoff as a Percent of Estimated Precipitation	X = Inhabited by Prehistoric Peoples	Estimated Prehistoric Population Within or Contiguous to Basin	Estimated Water Need for Human Consumption (Based on 3 Gallons per person per Day), in Gallons per Year	Estimated Water Available as Total Runoff, in Gallons Per Year*	Estimated Water Available as Total Runoff, in Acre-Feet per Year*
1	45.63	6814 3200	.041	D	4	3.92	2.20	2098 1205	46 26.4	20	48,652	4.3	x	514	584,730	682,000,000 392,000,000	2098 1205
2	14.3	4840 2780	.052	D	3	3.5	1.89	1575	110.1	18	13,728	11.4	x	197.5	216,262.5	447,000,000	1373
3	8.63	4042 2400	.057	D	3	3.0	1.79			16	7,362		x	696	762,120	239,000,000	736
4	9.02	4055 2260	.056	D	3	3.0	1.72	653	72.4	17	8,175	7.9	x	146	160,965	212,000,000	653
5	4.82	5450 2000	.151	T D	2	8.0	2.25	656	136.1	17	4,368	15.0					
6	.294	3500 2575	.215	D	2	2.0	3.88	626	2129	16	251	249.4	x				
7	1.038	3000 2190	.079	P D	2	3.0	3.41	1145	1103.1	16	885	129.3	x			28,900,000	89
8	1.32	3440 2140	.076	P D	2	3.0	3.46	528	400	16	1,126	46.8	x			36,800,000	113
9	3.065	4250 2310	.131	D	3	3.73	3.97	494	161	16	2,615	18.8	x	207	226,665	85,200,000	262
10	6.4	4690 2230	.099	D	3	4.5	3.34	1649	258	16	5,460	30.2	x			17,750,000	546
11	.708	3320 2245	.118	D	2	3.0	4.12	506	715	16	604	83.7	x			19,500,000	60
12	1.097	2857 1720	.123	D	3	3.25	3.26	737	672.1	14	819	89.9					
13	2.76	2997 1690	.129	T	2	3.0	2.00	2120	768	14	2,059	102.9					
14	3.42	2030 1567	.019	P	3	3.33	3.05	822	240.4	12	2,189	37.5					
15	2.01	1930 1567	.018	P D	2	3.0	2.57	1064	529.4	12	1,286	82.7					
16	.798	1840 1567	.025	P D	2	3.0	4.0	860	1077.7	12	511	168.2					
17	24.99	2872 1620	.018	P D	4	3.55	2.67	822	32.89	11	14,651	5.6					
18	4.87	2783 1825	.041	T	3	3.5	3.20	1067	219.1	12	3,117	34.2					
19	4.91	2600 1760	.043	T D	3	3.75	3.50	1320	269	11	2,878	45.9					
20	10.8	2783 1750	.041	T D	4	3.03	3.16			11.5	6,622						
21	10.68	4690 2160	.091	D	4	3.46	3.66	951	89	16	9,111	10.4	x	(basins 7 - 11 include this one)			
$\bar{x}$	7.69																

*The numbers used here are based on field runoff determinations where runoff 10% estimated precipitation; where runoff measured was 10% estimated precipitation, the figure used for "estimated water available as total runoff" is 10% of the estimated mean annual precipitation. Number (in gallons) are rounded-off approximations.

displayed in the heads of tributaries. The geologic factors significant in this are what one might expect, with dendritic patterns dominating in flat-lying Tertiary volcanic, volcaniclastic, and interbedded sediment - volcanic sequences. The major streams on coalesced alluvial fan - bajada complexes commonly display a parallel pattern relative to each other, but low-order elements of the network typically display dendritic patterns. Trellis patterns, wherever developed, typically have done so in Precambrian slates, phyllites, and schists that have steeply dipping, well-developed foliation planes. However, one trellis network is developed in a dissected sequence of volcanics and interbedded sediments (Basin 13).

One goal of this investigation was to test the postulate that trellis drainage networks, because of more quickly peaking runoff characteristics, were less desirable to prehistoric peoples as habitation sites because water would be available less frequently, and when available, simply less useful because of the flash-flood nature of runoff. Although none of the trellis network basins show signs of prehistoric habitation, only four such areas exist, and the size of the sample does not seem adequate to confirm the hypothesis. Moreover, it would be desirable to also test the assumption that runoff in trellis network basins does, indeed, peak and diminish more

quickly than runoff in other basins within the test area that are of comparable size but differing drainage geometry. No test of this assumption, save gauging, will confirm or disprove it.

Therefore, the role of trellis drainage, per se, as a negative factor in human settlement in prehistoric times is still open to question. Common sense prompts one to note, however, that flat-lying alluvial or otherwise constructed areas may have been more useful or desirable, particularly for any agricultural activity. An abundance of such areas existed. Perhaps a workable alternative hypothesis is that, all other factors being equal, these sites were simply preferred over those areas characterized by high relief and underlain by steeply dipping, foliated metamorphic rocks or other geologic conditions producing trellis drainage patterns.

Mean Annual Runoff

Prior to commencing investigations of the drainage basins selected for study, the field technique of Hedman (1970) was tested in several localities within the test area where gauging stations provided accurate runoff data. This allowed the field workers to gain familiarity with the process of identifying the bedforms and measuring the pertinent characteristics of stream channels. Runoff data could then be

checked to determine whether or not the data generated by the measurements taken were in agreement with those provided by the gauging records. In this process, one unexpected problem inherent to the approach became apparent. Precipitation prior to, and throughout the duration of this investigation was abnormally low, hence the bedforms were not subjected to the intermittent re-shaping and "maintenance" that runoff normally provides. This, coupled with the bedform-degrading activities of cattle, trail bikes, motorcycles, and other vehicles often made location of undisturbed channel sections suitable for measurement an impossible task. This problem was a constant companion throughout the course of fieldwork.

Table 3-III indicates that mean annual runoff values determined ranged from 494 acre-feet per year (Basin 9) to 2120 acre-feet per year (Basin 13). Further examination of Table 3-III shows, however, that these raw data pose a few problems; it's worth noting two examples. First, in Basin 1 (Baby Canyon), runoff measurements were made at two different times in two different localities (and one must remember these are measurements taken in <u>dry</u> channels). One, at the mouth of the basin yielded a mean annual runoff of 1205 acre-feet per year; the other, approximately 1.25 miles upstream, yielded 2098 acre-feet per year. No observable geological reason for this difference is evident, and the discrepancy seems far

greater than should be reasonably expected over a short distance in a master stream draining a basin of greater than 45 square miles. This is perhaps the most glaring example of inconsistency in runoff determinations made in the field during this investigation.

A second obvious problem appears if runoff data from different basins are compared. For example, the runoff from Basin 13 (area -- 2.76 square miles) was measured as 2120 acre-feet per year, essentially the same as that from Basin 1 (area -- 45.63 square miles and using the <u>higher</u> of the two runoff determinations, 2098 acre-feet per year). Such comparisons appear to be essentially meaningless, however. A more meaningful characteristic, the mean annual runoff per square miles, or unit runoff, was calculated for each basin. It has been shown by Hadley and Schumm (1961:161-162) that the relationship between mean annual runoff per unit area and drainage basin area in a region drained by intermittent or ephemeral streams shows a reduction in unit runoff as drainage area increases. A plot of the apparent mean annual runoff per square mile versus drainage basin area for the basins examined in this study is shown as Figure 3-3, and generally conforms to expectations.

As a further test of the runoff determinations, calculations were made of the estimated precipitation in all basins.

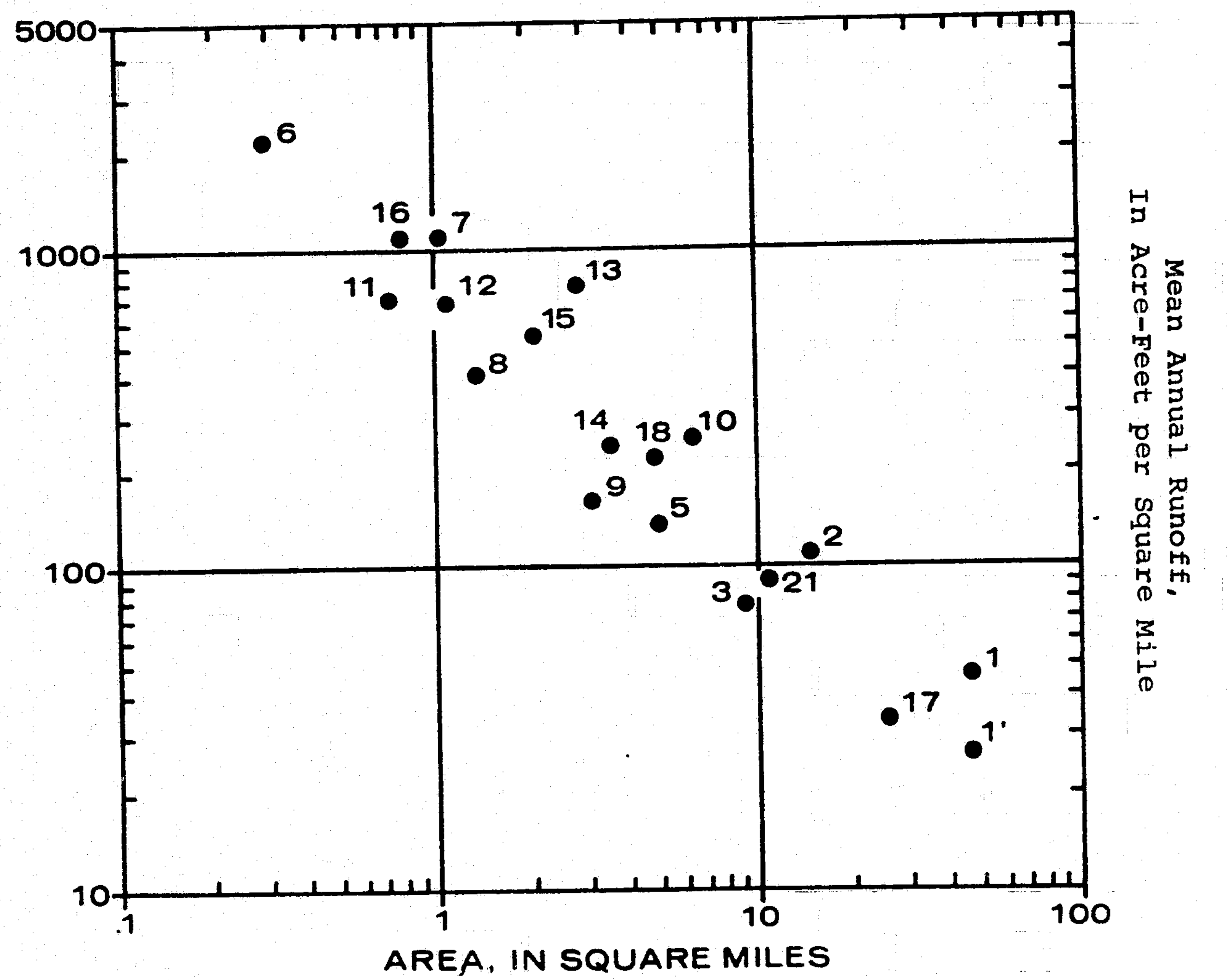


Figure 3-3. A Log Plot of the Apparent Mean Annual Runoff. In Acre-Feet per Square Mile, Versus Drainage Basin Area, In Square Miles. Numbers Refer to Drainage Basins

The annual precipitation figures utilized in these calculations were taken from the isohyetal map, WR-1210-A, prepared by the U.S. Department of Commerce, Environmental Science Services Administration, Weather Bureau, Western Region, and based on climatological data for the period 1931 to 1960.

As a general rule in this region, approximately 10% of precipitation can be expected to end up as runoff (William Meyer, personal communication). Calculations of runoff (determined in the field) as a percentage of estimated precipitation were made for each basin and the results are tabulated in Table 3-III. Values obtained generally exceed the 10% "norm," with some extreme values being glaringly obvious: Basin 13 -- 102.9%, 7 -- 129.3%, 16 -- 168.2%, 6 -- 249.4%! A plot of runoff as a percentage of precipitation versus drainage basin area (Figure 3-4) shows quite clearly, however, that although the values noted above are unrealistically high, they are part of what appears to be a systematic relationship between these two variables, namely that as drainage basin area decreases, apparent runoff as percent of precipitation increases. The similarity between the relationships portrayed in Figures 3-3 and 3-4 prompts the writer to emphasize the word "apparent" as used with any runoff data, for it seems obvious that in the cases of the smaller drainage basins, the data are misleading. More

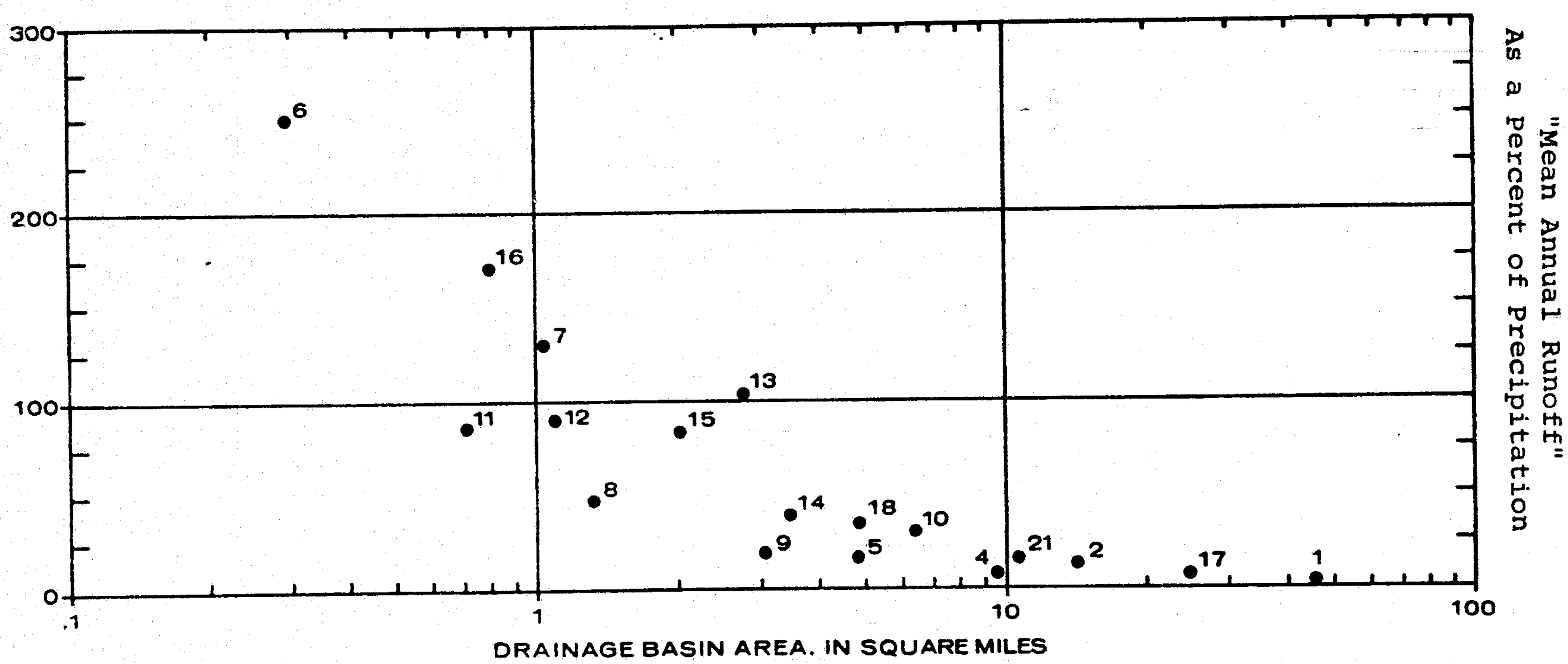


Figure 3-4. A Semilog Plot of the Apparent Mean Annual Runoff as a Percent of Estimated Precipitation Versus Drainage Basin Area in Square Miles. Numbers Refer to Drainage Basins

important, however, is the fact that these relationships suggest that if further field studies are undertaken to refine the technique, raw data on channel dimensions obtained in the field can possibly be processed to obtain more accurate estimates of mean annual runoff, especially of basins of relatively small areal size. This possibility is discussed in a subsequent section entitled "Recommendations for Future Work."

Evaluation of the Technique for Determination of Mean Annual Runoff

Problems and Their Causes

Certain facts from both the field work carried out in this project and from the literature on hydrology merit some discussion. First, the surface runoff, or discharge, at a given point in a flowing stream can be determined by measuring the width, depth, and velocity of flow, or as the relationship is more frequently expressed,

$$Q = w\ d\ v$$

where Q equals the discharge, w is the width of the stream, d is its depth, and v is the velocity of flow. Since channels typically are not pure geometric forms as seen in cross-section, nor is velocity of flow uniform throughout the channel, operational use of the above equation is somewhat more complicated

than it would appear, nonetheless, discharge measurements are routinely made. The technique for determining mean annual runoff employed in this study can be examined in the light of the above.

The technique looks only at the factors of width and depth, or cross-section area of the channel, and therefore does not reveal anything about variations in velocity of flow from point to point, even though the channel dimensions are sensitive to such variations. More significantly, it can not reveal any information concerning variations in flow from time to time. Such variations result from the complex interplay of many factors including the amount of precipitation, its distribution in time, other meteorological/climatological factors, the area of the basin, nature of the underlying materials within the basin, topographic characteristics, and vegetation. The interaction of these factors determines both the relative proportions and the absolute amounts of runoff, infiltration, and evapo-transpiration occurring within the basin, as well as the way in which this hydrologic output varies through time.

The potential for variation outlined in the preceding discussion may be at least partially illustrated by the following hypothetical example. A small basin developed in predominantly impervious bedrock may have a channel whose dimensions

are comparable to those of a stream draining a much larger area. The former may flow exceedingly rarely, though violently, whereas the latter could flow for the major part of the year. This hypothetical example assumes greater significance when one notes (as has been pointed out earlier) that Basin 13, with an area of 2.76 square miles, produced an apparent runoff of 2120 acre-feet per year, and Basin 1, with an area of 45.63 square miles, produced, according to the highest estimate, a comparable mean annual runoff of 2098 acre-feet per year. The hypothetical case and the example given from the field investigation seem virtually identical. Futhermore, the runoff measured for Basin 1 does appear to be a realistic estimate, although perhaps on the low side, whereas that measured from Basin 13 does not appear to be realistic (runoff determined to be 102.9 percent of estimated precipitation). Thus, it can be suggested that application of the method of Hedman (1970) to estimate mean annual runoff, in its present form, will yield both good and bad results, with the frequency of the latter increasing as the size of areas draining into the measured channel decreases.

Recommendation for Future Work

The original work plan for this project called for field examination and measurement of channel areas at many of the

gauging stations located on intermittent or ephemeral streams throughout Arizona. The purpose of this field work was to determine the relationship between channel dimensions and mean annual runoff as gauged. Then the relationship between these variables as determined in Arizona could be compared to the data generated by Hedman (1970) for similar streams in California, and perhaps a composite, refined set of relationships could be developed that incorporated the data from both studies.

Very early during the course of the field work, some of the already discussed shortcomings of the approach devised by Hedman (1970) became apparent. The inconsistencies among readings within a single basin were the most obvious, but the unrealistically high runoff values from small basins were also significant. The standard error of estimate for ephemeral or intermittent streams, given as 29 percent by Hedman (1970: E13), went far toward explaining the former; however, the latter problem was unresolved. As data accumulated, the systematic relationship between basin area and mean annual runoff, unit-runoff, and runoff as a percent of estimated precipitation became clearer and suggested that as basin size decreased, runoff and related values determined from the field work became less reliable.

It is significant to note that the sample of basins utilized by Hedman in devising the field technique differs markedly from the sample studied in this project. The twenty basins examined by him (Hedman 1970: Table 1: E3-E5) range in area

from 12.2 to 1693 square miles; the mean area is slightly greater than 275 square miles. In this study, n=21, the range in area is from .294 to 45.63 square miles, the mean area is 7.69 square miles. Given this basic difference in the nature of the two samples and the apparent effect of variation in basin size relative to runoff generated, it seems clear that simply repeating the work of Hedman will neither resolve the problem nor refine the technique.

It is our opinion that the most productive approach will be to establish a number of test basins in a region in settings that display variation in drainage basin area, relief, underlying materials, network geometry, and so on. Emphasis should be placed on smaller basins, or ones of sizes essentially comparable to those examined in this study. Within each basin both runoff gauging and precipitation gauging stations should be established and monitored. At the very least, accurate information on the minimum amount of precipitation needed to initiate runoff and actual runoff as a function of both precipitation and basin dimension (and other characteristics) would be obtained. Coupled with data from larger basins that are already gauged, a more comprehensive and potentially useful statement of the relationships between basin characteristics and hydrologic output could be produced. It is at this point where the initially contemplated study of gauged ephemeral or intermittent streams in Arizona becomes available.

3.2.2 Applications of Imagery to Hydrologic Analysis

Another objective of the study was to evaluate the relative utility of various forms of imagery as sources of hydrologic information. Specifically, Skylab S-190A photographs were to be used as sources of such information, and their usefulness was to be measured against information obtained via Skylab S-190B photography, existing aerial photography provided by U-2 overflights, U.S. Geological Survey 7½ minute topographic map quadrangles, and limited low altitude aerial photography. Field reconnaissance to determine ground truth was to provide the standard against which all forms of imagery were evaluated.

The initial step in this process of analysis, that of drainage basin selection, was not carried out using Skylab photography as per plan for a number of reasons, the primary one being that no photography was available to the investigators at the inception of the project. As described previously, basin selection initially followed the lead of archaeological investigations, and upon receipt and examination of the U-2 photography, this investigator selected additional basins in which the comparative tests, as well as other analyses, would be made. No basins were selected for study solely from inspection of Skylab photography, however, this fact neither hindered

the course of the investigation nor does it affect the validity of the comparative studies that were carried out.

Methods and Approaches

The basic approach in the analysis was that each of the drainage basins selected for study would be examined utilizing the following data bases:

1) S-190A Skylab photography; approximate scale of 1:1,000,000 in original format; 1:500,000 in enlargements.

2) S-190B Skylab photography; approximate scale of 1:1,000,000 in original format; 1:500,000 in enlargements.

3) Existing high-altitude aerial photography from U-2 overflights; approximate scale 1:125,000.

4) U.S. Geological Survey Topographic maps; 7½ minute quadrangles; scale 1:24,000.

The above array of data bases provided a suitable range of scales at which drainage basins could be examined, the degree of detail shown by each data base meaningfully compared to the others, and by the addition of field reconnaissance, all forms of imagery could be evaluated in terms of how closely they approach the ground truth.

Operationally, once a drainage basin was chosen for study, the first step was to prepare an overlay map of the basin using the topographic map as a base (as described

previously under "Methods of Basin Analysis -- Laboratory Work"). In the case of most basins, this constituted the only complete picture of the entire basin. Within the basins, specific areas were selected for examination via both Skylab and U-2 imagery. Typically, more than one smaller area within a basin would be examined, however, in some basins no area was examined in detail beyond the level provided by the topographic map. Those areas chosen for detailed examination were selected because they appeared to represent a range of variables in terms of geometry of the drainage network, amounts of relief in the basin as a whole, degree of slope of the land surface, and apparent differences in the geology of the underlying materials.

In a few cases an entire basin was examined using all of the imagery available. Prior to such an examination, a quick inspection of the photographs would be made to arrange the order in which they would be examined -- from those showing the least apparent detail to those showing the most. This was done in order to not bias the viewer toward "seeing" something that had been seen in a photograph viewed previously.

Insofar as possible, the results of the comparisons are presented as a series of maps of the drainage networks or portions of them. The maps were prepared and drawn to a common

scale for ease of comparison using two instruments described in the following section.

Instruments Utilized

Two instruments were utilized in carrying out the examination of the imagery. Both were essential to this portion of the study.

The Zoom Stereoscope

A Bausch and Lomb Zoom 240 Stereoscope mounted on a Richards light table and housed within the offices of the Arizona Land Department was the chief instrument used in stereoscopic viewing of photography. This instrument has a continuously variable magnification range from 7X to 30X.

Overlays of drainage networks were prepared by placing transparent mylar over photographs and drawing with a finely-pointed pencil on the mylar. This approach was used in preparing maps from all the Skylab photography and from positive transparencies of U-2 photography borrowed from the Arizona Resources Information System office. Positive prints of U-2 photography were also used as a base for drawing maps, either on mylar overlays or directly on the photograph itself. The latter approach yielded the best results, at least in the sense of the ease and speed with which the sought-after details

could be examined and delineated.

The chief advantages of the zoom stereoscope are the following:

1) Stereoscopic viewing is possible. This was absolutely essential for the investigation, especially in examination of areas displaying low relief. The combination of steep slopes and low sun angles increases the visibility of drainage lines, but it does not necessarily enhance the accuracy with which the viewer can delineate them, and the absence of shadows in gently-sloping areas makes objective location of wash axes only possible if a stereoscope is employed.

2) The variable magnification allows the viewer to view the image, in stereo, at a magnification that is optimally suited to the details sought and to the quality of the image, and if features are being drawn either on the photograph itself or on an overlay, varying the magnification does not affect this process, i.e., the "viewed" image and the "drawn" image are always at the same scale.

A few disadvantages of the process outlined above are as follows:

1) Viewing through mylar that possesses one frosted surface for drawing is a disadvantage; the image is obviously degraded by interposing this material.

2) The level of detail seen in the photographs, especi-

ally the small-scale Skylab photographs, commonly far exceeds that which can be rendered on the overlay. Here, the width of the finest pencil line is often too great, moreover, it does not produce a clean line.

The Zoom Transfer Scope

A Bausch and Lomb Zoom Transfer Scope, housed in the offices of the Arizona Resources Information System, was also utilized. Single images can be viewed in a continuous magnification range from 1X to 7X, and the viewed image can be superimposed on another image, for example, that of a topographic map. The map image can be varied in scale through use of interchangeable objective lenses. Thus, through manipulation of these two magnification systems, plus another system that can "stretch" images to compensate for distortion, images from the viewing screen can be brought to a common scale with the map or other image, and information seen on the former may be transferred, i.e., drawn, on the latter.

The potential use of such an instrument is obvious, and it was used extensively to raise, and draw, images of drainage networks as seen on U-2 and Skylab photographs to a common scale of 1:24,000. U-2 photography was of a scale that enabled this to be accomplished in one step. The smaller scale of Skylab photography did not allow the scale of 1:24,000 to be

reached in one step, and two were required.

The chief disadvantage of the zoom transfer scope is simply that stereoscopic viewing is not possible, hence, keeping in mind all the advantages of stereoscopic viewing enumerated previously, it is clear that objective decision-making, particularly in low-relief, shadowless areas, ranged from being difficult to being impossible.

The "Ideal" Instrument

Quite clearly, an instrument that both enables the operator to view imagery in stereo and to draw it at scales capable of revealing all the available detail would be the ideal.

Results

Any presentation or examination and interpretation of results in a study such as this must be done extremely carefully. The details being examined were many; a potential infinity of such details exists, yet only a few could be checked through completely. In terms of the analysis and portrayal of drainage networks, the investigator had to evaluate the imagery in terms of what was "seen" via the photograph. Was it seen accurately? Was it seen completely? The question of what was *not* seen was equally important, as was the question

of what were the underlying reasons for either "seeing" or "not seeing" a particular feature.

One factor that cannot be evaluated with any degree of certainty is the operator/viewer error that may or may not enter into the accuracy of the results. The total sum ... image quality plus viewing instrument capability/quality plus the investigator's ability (plus eye fatigue and other factors) not only virtually defies quantification, but also suggests that even internal consistency within the process of analysis would be a seldom-attained ideal.

Summary of Imagery Results

Based on the results of detailed evaluation, described in full in Appendix B, a concise summary of the imagery analysis conducted is as follows:

1. The most useful format for detail -- U-2 photography.
2. The most useful Skylab imagery -- from the S-190B camera.
3. The least useful Skylab imagery -- from the S-190A; the blue enhanced photography was the least valuable format.
4. In general, the best of the Skylab photography increases the number of stream orders seen within drainage networks (relative to those portrayed on

7½ minute topographic map quadrangles), by one or two. The U-2 photography increases order numbers by two or three.

The most detailed results come from the U-2, which typically misses only relatively inconspicuous first- and second-order rills.

5. All formats approach ground truth most closely in areas of high relief, relatively steep slopes, and bedrock covered only by sparse vegetation.

3.2.3. Water Availability and Prehistoric Water Need

Another goal of the project was to evaluate what, if any, impact water availability had as a limiting factor on population size and settlement patterns within the study area. It is recognized that any estimates of water availability derived from present-day hydrologic conditions do not necessarily reflect its availability to prehistoric inhabitants, yet the present-day data are the only starting point for approaching this question.

Estimates of prehistoric populations have been made for those drainage basins that were inhabited and estimates of the water needed to sustain such populations have been calculated (see Figure 3-3). Utilizing either the actual mean annual runoff determined in the field or a hypothetical runoff

calculated as 10% of estimated precipitation for the basin (whichever is smaller), the total amount of water available for each region was calculated (Figure 3-3, water available). It is quite evident from the data, that even adopting this most conservative approach, if past conditions were essentially comparable to those of the present day, the total amount of water available far exceeds projected needs in all locations by factors so large they're not worthy of calculation. Furthermore, although no estimates can be made of water needed to sustain the agricultural activity in prehistoric times, the estimated total amount available seems more than adequate to accomodate this additional need. However, there is no way in which this total amount of water available can be translated into information that tells something about when, how often, and for how long, water would be available.

Thus, only a partial answer to the question of water's role as a limiting factor can be obtained. The total amount of water available in all regions was evidently more than adequate to meet needs, and if its temporal availability was favorable, either as a result of natural causes or by human provision (i.e., water storage), its role as a limiting factor was minimal. One is tempted to add that the very fact of prolonged human habitation in an area argues very convincingly for the virtually continuous availability of water. If this

is an acceptable line of reasoning, it can follow that in those areas inhabited, the quantity of water had no limiting effect on the population size.

3.2.4. Summary of Hydrology Results

In summation, the hydrology-geology studies conducted during the course of the project fulfilled all but one of the stated goals projected at the onset of work (see Sec. 1.1).

The identification of surficial geological types was carried out by the examination of Skylab coverage (SL4, S190A and S190B), ancillary ground truth studies and U-2 imagery interpretation. Minor discrepancies were noted between the photographic interpretation and the ground truth results, and these were generally attributed to seasonal variations and the time of day during which the photos were taken. In addition, a problem of resolution, even with the S190B coverage, obfuscated the possibility of defining the finer geological structures from photo interpretation alone. Of the imagery utilized, undegraded U-2 imagery appears most successful for photographic mapping of geological features, especially the finer structural units.

The definition of the geometric characteristics of selected small drainage basins was accomplished. Mean annual runoff was determined for each test basin. It was calculated

that the amount of water available far exceeded the projected needs of the estimated prehistoric population of any given basin. As with the surficial geologic mapping, the most informative Skylab format was S190B; however, the most successful analysis was conducted using U-2 imagery.

Ground truth operations identified several types of water management systems utilized by the prehistoric population. No system, including the extensive canal network of the Agua Fria drainage, could be identified utilizing either Skylab or U-2 formats. This was due primarily to the fragile nature of the systems, and the obscuring characteristics of the Lower Sonoran plant community. However, it was possible to predict with some accuracy those basins which most likely would have water management systems located within them. The projection of the presence of the systems was based primarily upon the geometric characteristics of the drainage basins and the topography.

3.3 BIOLOGY

The purpose of the biology studies was three-fold. First, to define the boundaries of the biological transition zone postulated for the central Arizona region. The second and third goals of the study were overlapping. The project was to define and delineate the biological subenvironments

within the test area, selectively map them, and characterize the plant-water relationships within the region. To accomplish these goals, it was recognized that the larger environmental picture would be completed only through an examination of sub-environmental characteristics. It was in the definition of the sub-environments that the investigators originally felt ultra-high altitude or U-2 imagery would be most useful.

3.3.1. Delineation of Vegetation Communities

Vegetation can be considered as a "pattern of population and communities corresponding to a pattern of environments" (Whittaker 1970). Environments can be characterized by as many variables as can be measured; but the more factors that are simultaneously considered, the more complex the problem of environmental definition becomes. More frequently environments are defined by a few selected factors, such as temperature and moisture. It is instructive to consider the responses of vegetation to gradients of these factors, for such gradually changing conditions are more widespread than abruptly changing ones. Thus one can study patterns of vegetation along gradients of elevation, as from mountains downslope to valleys below. However it is clear that several other factors also change down this gradient: temperature increases, moisture decreases, and soil texture becomes finer. Each of these has

implications for plant growth and is in turn affected by other factors, such as wind, humidity, and slope exposure.

The greater the topographical diversity along an elevation gradient, the greater the diversity of microenvironments. A transect along a single mountain slope from 4500' to 1500' is less varied than one intercepted by numerous and diverse landforms. Since the transition zone has more physiographic diversity than either the Basin and Range Province or the Mesa-Canyon complex, one would predict that microenvironmental diversity could be higher and therefore vegetation patterns would be more complex.

A useful means of comparing zones is presented in Table 3-4. A total of 65 species of three life (growth) forms in the test region was analyzed. The remarkable high diversity of life forms in arid and semi-arid lands and the ecological and evolutionary significance for each plant association studied is discussed by Shreve (1964) and Brown and Lowe (1974).

Local topography affects local climate. Figure 3-5 illustrates a situation commonly found in the transition zone. At 2800 feet with similar soil characteristics, slope angle and rainfall, the soils in north-facing slopes retain more water and provide cooler growing conditions than soils on the south facing slopes. This is because the north slopes receive less solar radiation (= cooler) which in turn reduces the rates

TABLE 3-IV

SPECIES IN SELECTED LIFE FORMS

Physiograph Complex	Plant Association*	Life Form			
		Subshrubs	Shrubs	Succulents	Total
Basin and Range	<u>Desertscrub</u>:**				
	creosotebush-bursage	5	08	8	21
	paloverde-bursage	11	14	10	35
Transition Zone	sahuaro-paloverde-mixed cacti	26	18	11	55
	jojoba-false paloverde	25	11	8	44
Mesa Canyon	<u>Desert Grassland</u>	16	5	5	26
	Total Species Analyzed	30	20	15	65

*Data available on request.

**Since chaparral formed an insignificant portion of the study region and field work was limited there, only Desert scrub and Desert Grassland Communities are considered here.

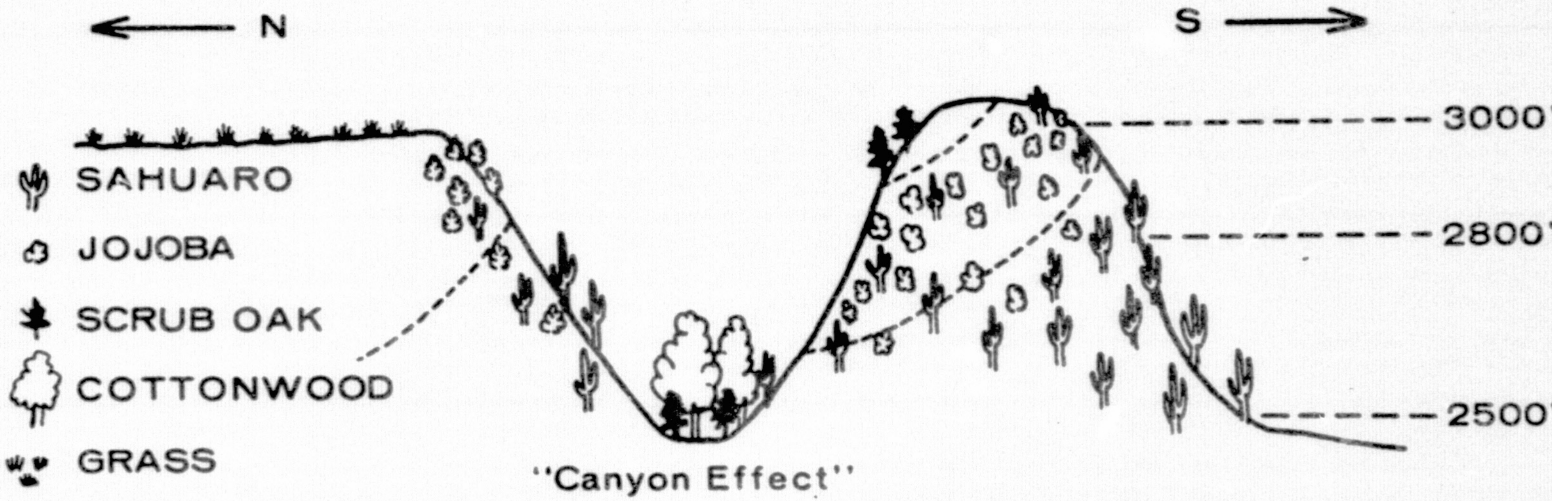


Figure 3-5. DISTRIBUTION OF PLANTS DUE TO SLOPE EXPOSURE AND COLD AIR DRAINAGE.

of evaporation (= moister). Thus species such as jojoba, false paloverde, and ocotillo (which are typical of higher elevations), will grow on north-facing slopes, while species of lower elevations, such as sahuaro, paloverde, and bursage, will grow higher on south-facing slopes. This pattern occurs on opposite slopes of canyons, which also demonstrate the "canyon effect." Cooler air slows along the canyon bottom and displaces warmer air upward onto the adjacent slopes; increased runoff and lower evaporation result in more moisture in the canyon bottoms. Thus species representative of plant associations of higher elevations (i.e., scrub oak) as well as distinctly riparian species (i.e., cottonwood) which requires more water, are found along these drainage channels.

3.3.2 Definition of Sub-Environments

Desert scrub associations do not conform to the boundaries established for the physiographic complexes established for the description of the test region (Figure 2-1). The plant associations of the Basin-Range Complex and those of the 'transition zone" are predominantly of desert scrub. The bajada soils which predominate in desert scrub regions, tend to grade from coarse and porous soils on upper bajadas to fine and relatively impernable soils on lower ones. Rock and gravel decrease as silt and clay increase, thus resulting in less

moisture available for plants. This in turn reduces both kinds and densities of plants able to be supported.

Desert scrub associations of lower elevations interdigitate with those of higher ones, depending on local edaphic and topographic conditions. For example, some plant species characteristic of the paloverde-mixed cacto association intrude upward along ridges and warm south-facing slopes among species of the jojoba-false paloverde-octillo association, which finger downward along drainageways.

The upper elevational limits of most desert species vary from species to species depending on the genetically determined tolerance limits for each (Lowe 1964 after Shreve 1951). This upper limit is usually the duration of cold temperatures, particularly the length of the winter freezes which kill seedlings. The sahuaro cactus reaches its limit where the duration of freezing temperatures throughout a night, the following day, and the following night occurs. This coincides with the northern limit of the Sonoran Desert and with the vertical limit of desert vegetation on mountain slopes and table lands (Turnage and Hincklye 1938). The lower limit usually occurs as moisture becomes limiting.

The Basin-Range Province is characterized by generally widely scattered shrubs with short trees usually confined to drainageways and rockier bajadas. Cacti occur throughout,

but reach maximum diversity and abundance on rocky bajadas and hills. The creosotebush-bursage and paloverde-bursage association occur here.

The transition zone contains more buttes, mesas, eroding mountain slopes, and drainageways of varied soil structure than either the Basin-Range or Mesa-Canyon complexes. The greater diversity of parent material, comprising these eroding landforms produces greater variety of physical and chemical characteristics of soils, which in turn affect plant distribution. The mixed paloverde-cacti associations increase in species richness from lower elevations to higher along gradients of increasing percentages of rock and gravel in the soils. Plant densities also increase, producing a more complete vegetation coverage. Three subzones have been designated: 1) the paloverde-bursage associations, with scattered cacti and low diversity of sub-shrub, 2) Sahauro-paloverde-bursage associations (typically the Arizona Upland Division of Shreve 1964), characterized by the highest diversity of cacti; with more species of subshrubs, taller and denser trees on slopes and flats, and the most well-developed riparian vegetation in major drainages; 3) jojoba-canotia associations usually on steeper slopes at the upper elevational range of the paloverdes and sahuaros, frequently with local stands of ocotillo, characterized by a lower diversity of cacti, but the highest richness

of sub-shrubs, a growth form characteristic of xeric mesas, slopes and ridges in upper desert and grassland habitats.

Riparian associations form distinctive climax associations which are locally modified according to water availability and man-modified factors. Those present in the test region include:

1) Broad-leafed Deciduous Riparian Woodland, with locally varying densities of Populus, Salix, Fraxinus, Platanus, Juglans and Prosopis-Narrow-leafed Riparian woodlands, with Prosopis, Acacia, Chilopsis, Celtis, Morus, and rarely Sapindus (in drier washes of higher elevations, particularly in Grassland and Chaparral).

2) Riparian Scrub, with Baccharis glutinosa, B. aarothroides, Hymenoclea monogyra, and H. salsola along sandier, more mesic floodplains in lower zone extends into grasslands; thorny shrubs, with Brosopis, Acacia (constricta at lower, greggii throughout), Cercidium (floridum and microphyllum) Condalia, and Lycium extend into grasslands.

3) Tamarix disclimax associations represented locally by various pockets of tamarisks along major drainages, i.e., Agua Fria, New River, etc.

The Mesa-Canyon Complex occurs in the Upper Sonoran Zone and contains Desert Grassland, and Chaparral Communities and

the ecotones between them. Elevations range from about 3000' at the southern end of Perry and Black Mesas to about 4500' along the slopes and peaks of the Black Hills to the north and the Brooklyn Peaks to the east. Elevations along the Agua Fria River range from about 4000' to the north at Cordes Junction to 2100' at its southern junction with Squaw Creek. Riparian associations other than in the major riparian woodlands of Perry Mesa, which drain the adjacent foothills, are less diverse than those of the transition zone. Chaparral species intrude into grassland habitats along these drainages and on north facing slopes. Chaparral vegetation becomes more dense at elevations above 4500' and is well-developed above 5000'. Although no significant juniper woodland occurs in this region, junipers grow in variable densities at higher elevations and are scattered throughout the mesas and on slopes along minor drainages.

The highest diversity of woody vegetation in the desert grassland complex is due primarily to the occurrence of riparian habitats, major canyon woodlands, and minor runoffs with slight relief along mesa top and slopes of gentle, low hills, foothills to chaparral habitats. Chaparral species penetrating the grassland region in riparian habitats include: <u>Berberis</u>, <u>Quercus turbinella</u>, <u>Ceanothus greggii</u>, <u>Rhanmus crocea</u>, <u>Cercocarpus montanus</u>, <u>Rhus trilobata</u>, and <u>R. ovata</u>.

The mesas are covered with a disturbed mixed shrub-grass disclimax association consisting predominently of invasive species: mesquite, catclaw acacia, mimosa; yucca, prickly pear, cholla, snakeweek, globemallow, and thistle. There is little doubt that a more uniform grassland covered the area within recent times (perhaps as late as the 1880's). Junipers are invading the region judging from the young age of most individuals encountered.

The canyons support distinctive riparian gallery forest vegetation along the stream channels, composed of several species which typically grow in greater abundance at higher elevations (Platanus, Fraxinus, Juglans). Due to the size of the canyons and steepness of slopes, as well as to opposite orientations (north- vs. south-facing slopes) a considerable diversity of woody plants and succulents is supported, often sharply distinctive from one side to the other. The cold air drainage phenomenon supports chaparral species on northern-facing slopes and distinctive riparian vegetation along channels; the warmer, drier south-facing slopes support a variety of subshrubs and some varieties of desert scrub.

3.3.3 Application of Imagery to Vegetation Analysis

Study of S190A and S190B format imageries began with a synoptic survey to determine which was more efficient for

distinguishing topographic features. A more detailed comparative study of each format followed. Specific areas, usually near archaeological sites, were chosen in each physiographic zone and imageries of natural topographic, man-made, and vegetation features compared. The results were compared with observations of U-2 and low-level black-and-white prints. S190A, S190B, and U-2 formats were studied using binocular stereoscopes, a zoom stereoscope with maximum magnification of 30x, and a zoom transfer scope. Low-level prints were studied with hand lenses and unaided eyes. Enhancement facilities were unavailable for study of S192 formats.

The results are presented in Table 3-VIII (enclosed). Most imagery was clear and useful for determining topographic features. S190A color was more important than S190A infrared for defining natural topographic features, but it was not as clear as the S190B format for determining man-made features. S190B color and infrared were equally good for most analyses, except for man-made features, especially jeep trails and dirt roads, which were more evident on color than on infrared. Both U-2 and low-level imageries clearly defined most features investigated; however, their use presented some disadvantages as discussed below.

All formats were useful in defining major topographical regions and were helpful in familiarization with topographic

maps used in ground truth activities. They were used to develop an efficient field itinerary, and they increased field efficiency by facilitating interpretation of topographic maps which can be confusing in diverse areas.

Vegetation patterns were viewed from regional and local perspectives. Using knowledge of general plant distribution patterns, the investigator looked for: 1) different vegetation types and densities in different topographic regions; 2) more vegetation on north-facing than south-facing slopes and canyons; 3) more vegetation in canyon bottoms than on slopes -- more on lower than upper portions of those slopes; 4) more riparian vegetation in major drainages than in minor ones. Neither Skylab nor U-2 imagery was very useful in determining vegetation types, and vegetation density information was relatively scanty for all S190A and color S190B formats.

In general none of the 190A photos were useful in determining major vegetation types; imageries of desertscrub, grassland, and woodland were indistinguishable although high montane forest was noted. Although some riparian vegetation such as dense stands on broad floodplains was distinguished, most was not. 190A infrared format suggested patterns of increasing plant density along elevational gradients from valleys to mountain peaks.

S190B infrared format gave consistently useful information. It showed clear differences in plant densities or riparian and non-riparian habitats along the elevational gradients. It more clearly defined differences in slope vegetation density. It often showed vegetation in dark areas which color format showed as shadows. This was especially true in regions of high relief such as lower mountain canyons and mountains. In steeper canyon systems, such as where the Agua Fria River flows through the Perry Mesa Complex, it is difficult to distinguish riparian plants from the dense slope vegetation with color format but easier with infrared; inner bends in the drainages where sand bars are covered by plants are easily detected with infrared. Blue-enhanced color of S190B has much less of the light-dark contrast useful in viewing patterns of plant distribution and lacks the reddish indicators of plants provided by infrared.

Because each U-2 print covers a smaller area, U-2 formats are less efficient than the S190's for lab studies of broad regional patterns. However, they are better for determining vegetation associations on a local scale and are particularly accurate for riparian vegetation.

Although information content is high, overall utility of low level prints for this type of vegetation analysis is low because each print covers such a limited area. It is difficult

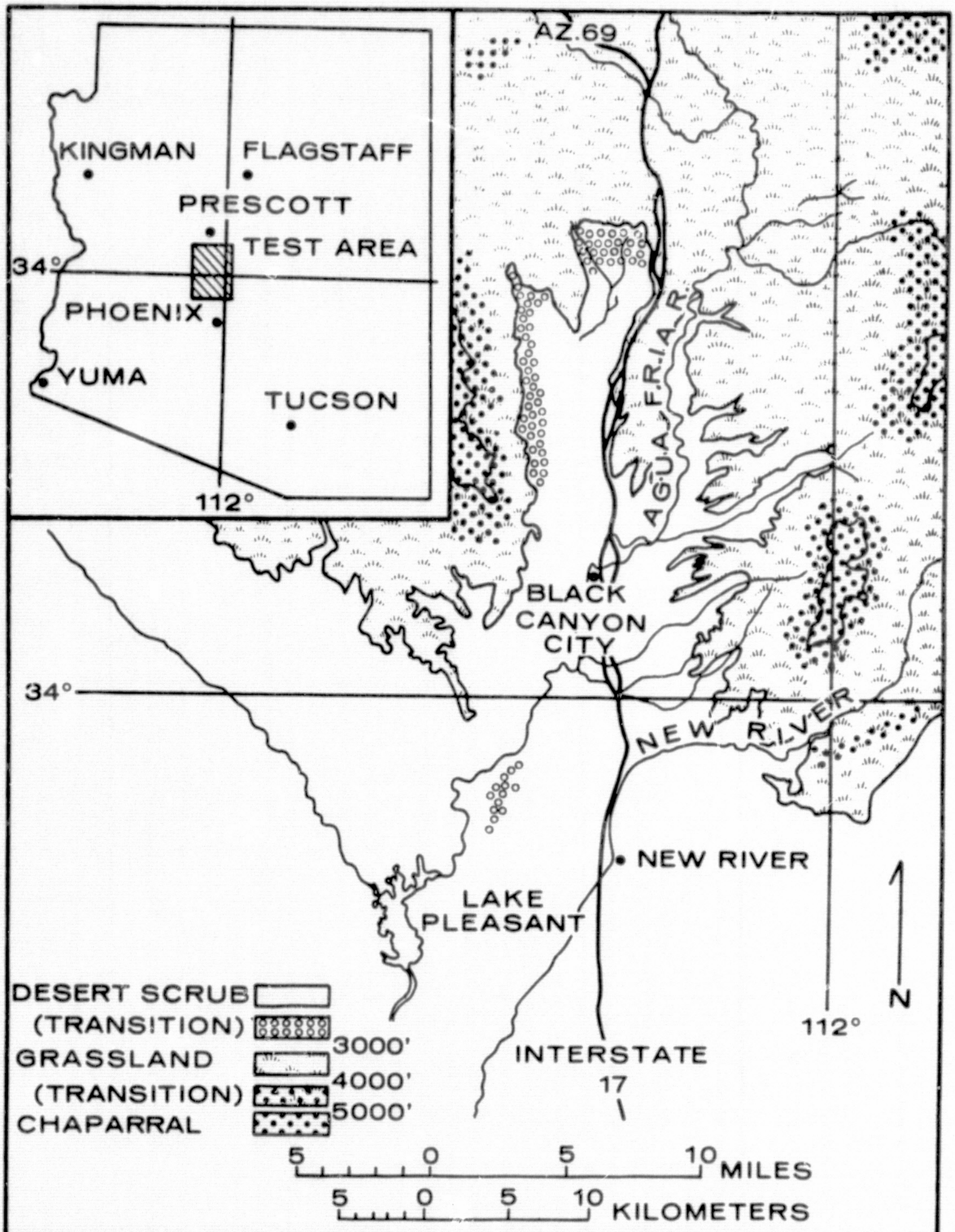


Figure 3-6. MAJOR VEGETATION TYPES OF THE CAEP STUDY AREA.

to locate features in the photos on topographic maps or on the ground unless the locality is very distinctive.

The vegetation map included in this report (Figure 3-6) was drawn after using S190 formats, topographic maps (2 degree and 7½' sheets), and field verification of particular areas. The Skylab photos were used with a zoom-transfer scope to: a) map physiographic features of vegetational significance more easily and more accurately than by using contour intervals of topographic maps; and b) define boundaries of vegetation types using limited field work with greater efficiency than would have been possible with extensive field work alone. Occasional innacuracies in topo maps were corrected by direct mapping from photos.

Three predictions of vegetation patterns made from study of S190B Infrared formats and previous knowledge of plant ecology were later confirmed by ground truth: 1) Squaw Creek Mesa top was desert grassland with scattered shrubs and succulents; 2) canyon vegetation in tributaries of New River draining New River Mesa contained some evergreen and Chaparral species; and 3) vegetation density was greater on north-facing than on south-facing slopes of Squaw Creek Canyon.

3.3.4. Summary of Biology Results

In conclusion, the results of the biological studies indicated less usefulness for ultra-high altitude imagery in

the determination of Upper and Lower Sonoran plant communities than those achieved in the geological analysis. Although the results were much less consistent, it was again apparent that the S190B format provided the most information of any imagery tested. It is felt that the S190A infrared coverage would have been useful if the coverage had occurred during either the flowering or fruiting seasons of the year.

The S190B imagery, in conjunction with ground truth operations, afforded the investigators the opportunity to grossly define the biological sub-environments of the test region. It should be noted that the most obvious sub-environment defined was the montane zone, with the desert zones blending into one another except for the riparian environments which were distinguishable.

It was not possible using any aerial photographic method to clearly define the boundaries of the postulated transition zone. This was largely due to the interrupted nature of the boundary over any given distance. The transition zone, from ground truth operations, was determined to be much less definable than originally anticipated and did not constitute a well-defined continuous belt between the Upper and Lower Sonoran zones.

3.4 INTRODUCTION

The primary goal of the archaeologists was to determine the types of agriculture employed by the pre-Columbian inhabitants of the test area. In doing so, the archaeologists were concerned with the water management systems utilized by the peoples, what they grew and under what climatic conditions they were operating. As readily noted, the tasks to be performed by the archaeologists were less dependent upon aerial photographic data than any of the other disciplines involved in the project.

The principal use of orbital coverage in the archaeological phase of the project concerned the delineation of specific drainage basins which, by the nature of their geometry, were estimated to be optimum agricultural regions. In turn, extensive and intensive ground operations led to the definition of water management systems. In addition, the archaeological aspect of the project was to provide the integrative function of articulating the various disciplines to focus on the problems of past environments and man-environment relationships.

3.4.1 Water Management Practices

Many of the archaeological sites identified in the test area have already been discussed. However, work on this project has resulted in the attainment of evidence of numerous types

of land use and water management systems. Systems similar in form and probably function have been noted throughout the prehistoric Southwest, with a variety of names being utilized by different authors to describe what often appear to be identical types. As a major focal point of this report concerns these systems, it is both useful and necessary to utilize a standard set of descriptive definitions for them. Those employed in this report derive mainly from Hack (1942), Woodbury (1961), and Hall (1974). Some changes have been made to more accurately reflect apparent functions of the systems in the project study area and some systems similar in structure and/or location which the above mentioned investigations have placed in the same category are defined here as separate systems, based on apparent variation in function within our particular study area.

Terraces

Terraces consist of masonry walls or piled lines of rock located on, and laying perpendicular to, a slope. In both the Upper Sonoran and transition zones, numerous natural terraces could have been utilized. Certainly the artificial or man-made terraces served the function of collecting and/or retaining soil in an attempt to create flat areas on a given slope which could then be used for farming purposes.

Terraces in this area are generally located on a slope of approximately 30%, with a range from 5% to 40%. Artificial terraces generally have walls constructed of unshaped boulders piled three or four courses high and average 20 meters in length, though in one location they are only four meters long (Ariz. N:16:85), and at another (Ariz. N:16:45) they average 35 meters in length, and one standing segment is constructed of dry laid masonry up to five courses high.

In this position of the study area terracing generally occurs on a slope of approximately 13% with ranges from 1% to 20%. (Some terraces in this area may have been misidentified; see below). All of the artificially constructed terraces in this zone were constructed of piled stones, ranging from one to several courses high. In general, they consist of 5-10 separate walls, 15-20 meters in length, with ranges of 4 to 85 walls and 2 to 60 meters in length.

Linear Borders

Linear borders appear similar to terraces in location and structure but are functionally different. They consist of lines of piled rock, usually, though not invariably, located on, and laying perpendicular to, a slope. In a few cases these systems were noted laying parallel to the direction of the slope, in an apparent effort to direct water to fields located

below the systems.

The major distinction between terraces and linear borders is that while terraces serve to create level areas behind the structures on the slopes on which they are located, linear borders are constructed so as to slow the flow of water and prevent soil erosion. Woodbury (1961) has noted that linear borders also served as a convenient mechanism for clearing rocks from fields as well.

In the general study area linear borders appear to have had two main functions: 1) they were constructed to slow the flow and increase absorption of water for the crops planted in fields where the system was located. This also helped prevent the destruction of crops by erosion; 2) linear borders acted to slow and/or direct the flow of water for use on crops planted in fields below the system. This also acted to prevent these crops from being covered by eroded soil. In this second type it appears likely that crops would have been planted between the rows of stones as well as below them.

In the Upper Sonoran zone data on these systems is generally lacking, although sampling error may be a factor.

In the transition zone linear border systems generally consist of 15 to 25 units ranging from 20 to 50 meters long. One notable exception is at Ariz. T:4:54b where there are 150 to 200 lines ranging in length from 100 to 150 meters (see

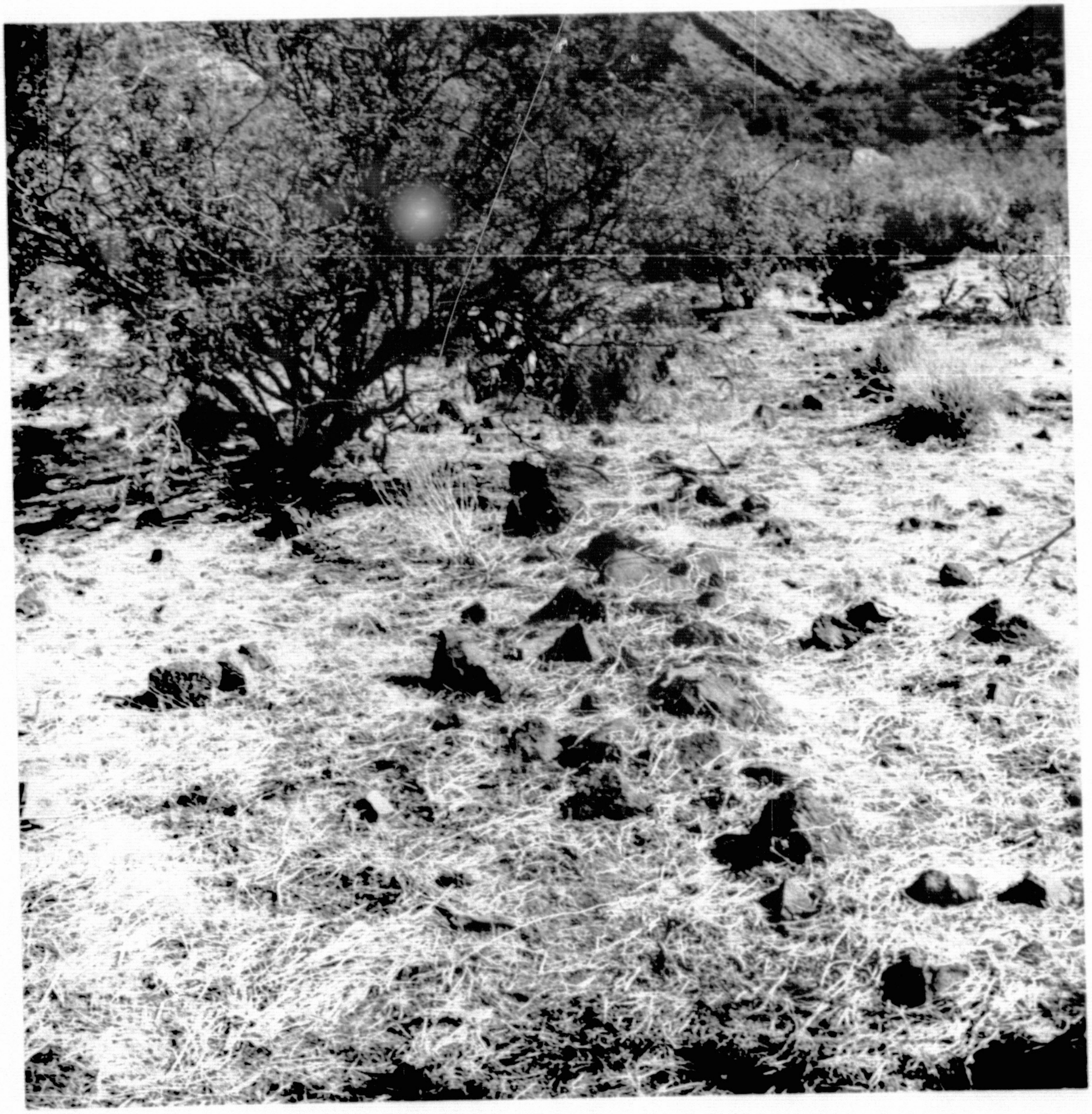


Figure 3-7. View of linear borders of Ariz:T:4:54 looking north

Figures 3-7 and 3-8). In this zone linear borders are consistently found on slopes of approximately 4%.

Grid Borders

Gridding is not considered here to be a distinctive type of system, but rather is perceived as a structural variation used in conjunction with both terraces and linear borders. Gridding occurs when a line of stones is placed perpendicular to a set of linear borders or terraces thereby creating a system of grids or squares. The functional purpose of employing grids in a system of terraces or linear borders appears to be the prevention of water from settling into low areas in a field and to more evenly distribute the flow of water over fields lying below the system. In the few cases where an entire system was gridded, the purpose appears to have been the impoundment of water in the grids for more complete absorption by the soil.

The gridding of the systems in the Upper Sonoran Zone is generally very limited. Gridding was employed in only one system of terraces in this zone and although in this instance it appears rather extensive, the system itself is unusual, occurring in association with the only evidence of possible canal irrigation in this zone.

In some instances in the transition zone, gridding was

Figure 3-8. Ariz:T:4:73A-row of grid borders

a minor component of the system, while in others it was used over much of the system. The extent of the use of gridding seems based on the expected behavior of water flowing over the fields. At Ariz. T:4:54c the system of linear borders is bounded on two sides by hills and on the other two by fairly deep washes. The gridding in this system was located along the edges of the washes and appears to have been present to prevent water flowing from the slopes, and that falling directly on the field, from flowing straight into these washes.

At Ariz. T:4:71 the system was located on a floodplain. The gridding here, used extensively between alternate pairs of linear borders, appears to have functioned to keep flood waters spread evenly over the fields.

Trenchera Fields

The definition used here is from Hack (1942) who defines trencheras as a type of terrace used in small washes and arroyos to retain soil and slow water for the purpose of cultivating in the wash.

One possible trenchera system was located in our ground truth operations. It is in the Upper Sonoran zone on the south rim of Baby Canyon. It is questionable as to whether this was a natural occurrence, as the "walls" located in the

wash consist of large boulders which could have conceivably rolled into the wash from the surrounding hillsides. However, since these "walls" do create areas suitable for cultivation, and because the immediate area is also characterized by extensive terracing and linear bordering, the wash is assumed to have been used for purposes of agriculture.

It should be noted that one of the major benefits of trenchera plots is that, even in extremely dry years, they will generally receive enough water to grow crops even when other fields fail. Because of this fact, it is notable that washes suitable for this type of agriculture were almost entirely neglected. This would seem to be indicative of two possible factors (or their combination): 1) available water for agriculture was not a major problem for prehistoric agriculturalists in the area and/or 2) they perceived the costs in building and maintaining such a system prohibitive with regard to potential benefits.

Check Dams

This term is used to describe structures which are similar in appearance and location to trencheras, but serve a different function. The major distinction lies in the realm of soil retention. Check dams, rather than creating farming plots, serve to slow or defer the direction of water flow out of the

stream in which they were located for use on fields located below the stream. Check dams could also be utilized to cause a stream to overflow its banks on to surrounding fields. Only very few small check dams have been noted in the project test area.

Fields Located on Flood Terraces and Floodplains

The purpose of locating fields in areas which are periodically flooded is to provide crops planted in such fields with a greater amount of water than would normally be received from rainfall and sheet flow alone. This provides a safeguard against dry years and raises crop yields during years of average precipitation. Once such a field is abandoned Hack (1942) reports that little or no evidence remains to indicate its previous function. This makes discovery of such fields difficult at best. If, however, one finds areas which could have been potential flood fields, there does seem to be concomitant archaeological data to support such a hypothesis. In the project study area these take the form of sherd and lithic concentrations on flood areas, piles of rock which have been cleared from such areas, structures on or adjacent to the hypothesized flood field, and the presence of petrogyphs on boulders and metates in these fields.

All available flood areas in the Upper Sonoran zone

appear to have been utilized, although two sites included as flood terraces (Ariz. N:16:66 and Ariz. N:16:67,68) may have been watered by runoff from the mesa top and canyon walls.

Cleared Land

Although many flood plains and terraces show evidence of clearing, and cleared areas have been noted in association with terraces and linear border systems these are not included under this heading. Rather, these are areas, identified only in the Upper Sonoran zone, on the mesa top. They are distinguished by having had stones and boulders removed from them. These areas are found where the exposure of bedrock is great. The small rocks in these areas have been piled onto the bedrock, presumably to create open areas suitable for farming. Also included in this category is an area near Lousy Canyon which was bordered on two sides by habitation sites of larger than average size (Ariz. N:16:16 and Ariz. N:16:17). This particular area appears to have had excellent potential as farming land that would not have needed alteration for utilization. It should be noted that other such areas occurred in the study area, particularly in the Upper Sonoran zone, but were not always recorded as potential agricultural systems. This oversight was due largely to the fact that there was not direct archaeological evidence (in terms of artifactual material re-

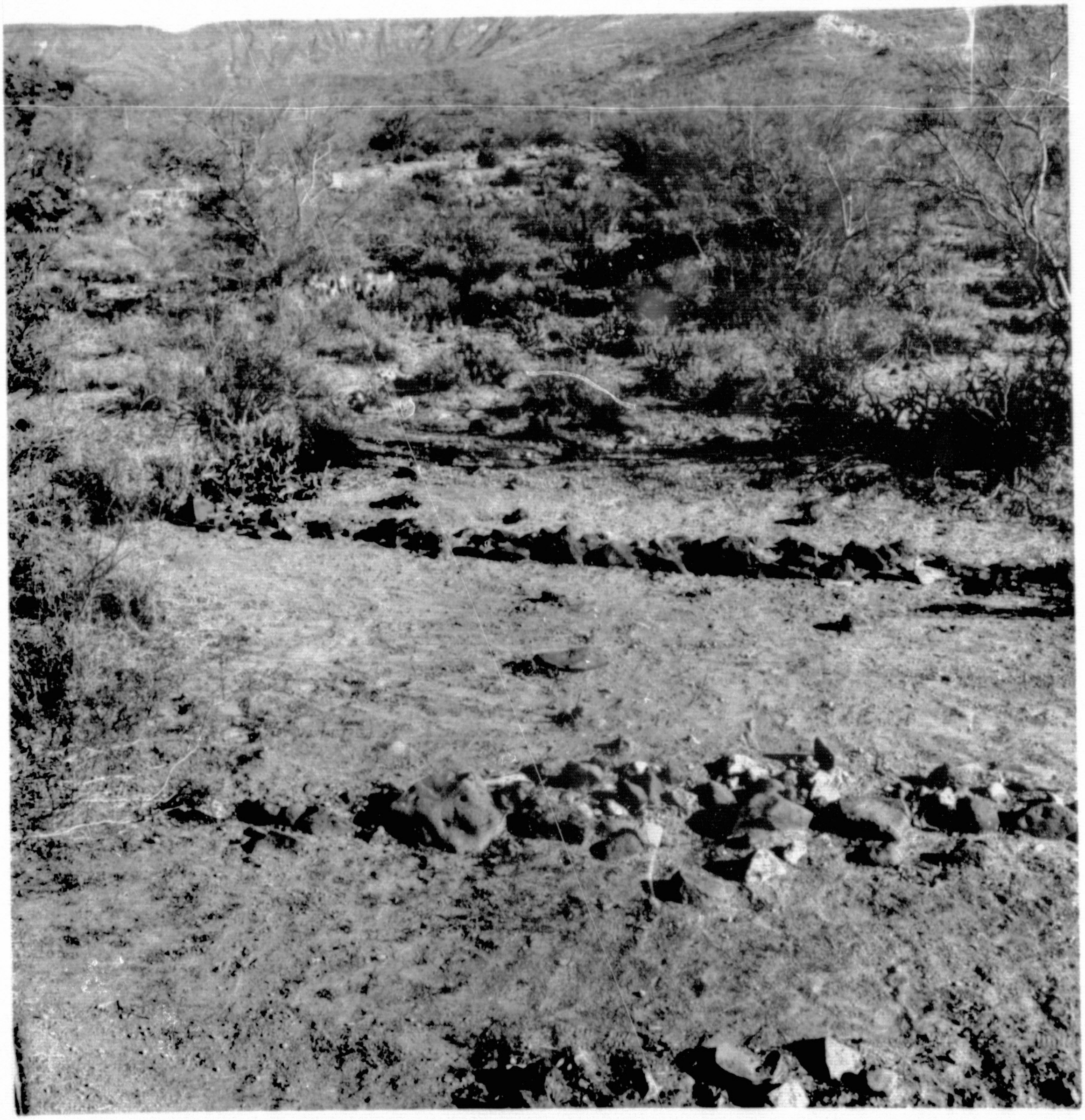


Figure 3-9. Ariz:N:16:88-garden plots (cleared land) associated with site to North

covered) for the prehistoric use of many of these areas (Figure 3-9).

Canals

Although feeder ditches, canals and canal systems have been reported throughout the prehistoric Southwest (mostly dating at post A.D. 1000) the best engineered and most extensive are those of the Hohokam, whose main occupation was in the Salt and Gila drainages. Extensive Hohokam canals have been recorded in the southern portion of the CAEP study area near Calderwood Butte (cf. Weed 1973).

In the one case where a canal-like structure was noted north of the Lower Sonoran zone (in the transition zone) it was found in association with the Hohokam Red-on-buff ceramics. Since this type of pottery was noted at only two other water management land use systems (those at Ariz. T:4:50 and Ariz. T:4:54) it appears likely that this "canal" was not associated with other systems. This "canal" is evidenced only by the presence of a shallow, narrow trench running through a habitation site. No test excavation was undertaken here.

Reservoirs

Very little evidence of reservoirs, i.e., structures which act to catch and retain water, have been identified in

the areas covered by our ground truth operations. In fact, the only structures located which appear to be reservoirs have been in the area of Lousy Canyon. These consisted of small, circular structures, often located on a steep slope. Of notable interest here is the fact that no structures which could be identified as reservoirs have been found in association with habitation units. Instead, when they did occur, they appeared to be either isolated features or in the case of the Ariz. N:16:76 complex, in groups. It would appear likely that all reservoirs may have been used strictly to catch and retain water for agricultural, as opposed to domestic use.

Waffle Gardens

Without question the hundreds of acres of "waffle gardens" which have been identified in the Calderwood Butte area along the Agua Fria are the most enigmatic water management/ land use systems encountered on this project. These are garden plots which were invariably located on gravel terraces above this major drainage system. Unlike many other field systems in the Lower Sonoran zone the waffle gardens could not have been irrigated by canals, nor could they have collected water from water sheds. They would have had to been used almost exclusively for dry farming. They consist of a series

Figure 3-10. Ariz:T:3:4—View of waffle gardens looking North

of contiguous square borders of rocks (hence the name) located on the long, relatively flat gravel terraces and ridges bordering the Agua Fria. They appear to have been constructed by removal of small stones littering the terraces which were then piled up to form the contiguous borders around cleared mineral soil. According to Nellans (1975) a number of these systems have small feeder ditches which are apparently located to channel overland flow from rainfall into the various individual system components (Figure 3-10). (An illustrative chart further defining specific situations in which systems were identified is to be found in Table 3-VI.)

3.4.2 Water Management System Keys

Based upon the results of the analysis of all photographic coverage a key table was constructed that could be utilized in the identification of water management and land use systems. It differed only slightly from the keys structured for the identification of site localities. The differences were the utilization of patterned linearity, drainage basin geometrics and shadowing as primary indicators. Only one characteristic, that of drainage geometrics, could be adequately discerned from the orbital coverage. It was obvious in the analysis of the photographic coverage, other than the Skylab data, that vegetational patterning was a key

indicator in the identification of hydroagricultural system localities. This was especially true with the canals of the Lower Sonoran zone, which were delimited by the regular linearity of paloverdes. Many of the prehistoric water control systems throughout the southern portions of the test area are still partially functional, and the indigenous vegetation of the zones tends to grow along the lines of rocks which outline the systems. By closely examining the U-2 and lower altitude coverage it was possible to discern patterning to the vegetational growth, albeit many times only short linear fragments.

When this information was used in conjunction with data supplied on the drainage basin geometrics, it was possible to predict system localities with some regularity. The geometry of the drainage basins, already discussed in the hydrology/geology section in detail, offered the best indication of both site and system location. It was demonstrated through ground truth operations that only specific types of drainages could be successfully modified by the prehistoric inhabitants. The "predictability factor," which will be discussed more fully later in the section, afforded the archaeologists the chance to eliminate several areas which otherwise might have required ground reconnaisance.

The shadowing effect, again only useful with the lower

TABLE 3-V

VEGETATION AND LANDFORM KEY

Vegetation Key	Land Form Key
1 - Ash	med. - medium
2 - Cottonwood	rel. - relief
3 - Ironwood	con. - considerable
4 - Sycamore	hg. - high
5 - Scrub Oak	mnt. - mountains
6 - Mesquite	
7 - Paloverde	
8 - Creosote	
9 - Jojoba	
10 - Juniper	
11 - Mormon Tea	
12 - Acacia	
13 - Bladderbush	
14 - Bursage	
15 - Greythorn	
16 - Compositae	
17 - Kremaria	
18 - Snakeweed	
19 - Umbelliferae	
20 - Grasses	
21 - Mistletoe	
22 - Agave	
23 - Yucca	
24 - Ocotillo	
25 - Cactus	
A - Saguaro	
B - Barrel Cactus	
C - Staghorn	
D - Prickly Pear	
E - Teddy Bear Cholla	
F - Hedgehog	
26 - Willow	
27 - Ceanothus	
28 - Mallow	

TABLE 3-VI

WATER MANAGEMENT AND LAND USE SYSTEMS IN THE TEST AREA

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
				Ariz. N:16, Mesa Top					
Linear Borders									
N:16:27	N-S 50m. E-W 20m	N. rim of Baby Canyon, Central		2%	SE 300m N:16:28	12 rms	Table land	South 200m	Bishop Creek
N:16:29	N-S 64m. E-W 4m.	N. of Baby Canyon, Central	12, 18, 23 25c & d	2%	S 450m. N:16:28	12 rms	Table land	South 600m.	Bishop Creek
Cleared Land									
N:16:16	N-S 55m. E-W 50m.	S. of Lousy Canyon, flats	8, 6, 15, 18, 12, 25D	4%	N:16:16	11 rms	Table land med. rel.	South 600m.	Larry Creek
N:16:17	N-S 45m. E-W 25m.	S. of Lousy Canyon, flats	6, 12, 25D	4%	N:16:17	14 rms	Table land con. rel.	SE 700m.	Larry Creek
N:16:42	N-S 64m. E-W 32m.	S. of Baby Canyon, flats	12, 18, 23, 25D	2%	N. 800m. N:16:46	37 rms	Table land	North 750m.	Bishop Creek
N:16:107	N-S 30m. E-W 25m.	S. of E. Tank Creek in flats	12, 18, 20, 25D, 25E	2%	No assoc.			North 700m.	Tank Creek
N:16:111		N. of E. Larry Creek		2%	W. 3.4km N:16:20	10 rms		South 300m.	Larry Creek

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
Flood Plains									
LA #1		N of E end of Lousy, on slope		8%	S. 1.8km. N:16:80	60 rms		West 20m.	Lousy Spring
N:16:9	N-S 55m. E-W 45m.	SW of Lousy Tank	12,18,20, 25C, 25D	4%	W. 750m. N:16:7	50 rms	Table land	North 100m.	Lousy Spring
N:16:106		S. of Perry Tank	12,18,20, 25D, 25E	1%	no assoc.		Table land	North 600m.	Tank Creek
Miscellaneous									
N:16:41	N-S 62m. E-W 30m.	N. of E. Central Baby Can.	6, 10, 12, 25C, 25D	2%	NW 1.1km. N:16:28	12 rms	Table land	South 200m.	Bishop Creek

Ariz. N:16, Rims and Bottoms

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
Terraces									
N:16:14	N-S 60m. E-W 70m.	N. terrace at mouth of Lousy	7, 6, 9, 12, 15, 25, A, C, E	40%	N:16:14	20 rms	Table land w/ mod. rel.	South 300m.	Lousy Spring
N:16:15	N-S 70m. E-W 45m.	N. terrace at mouth of Lousy	6, 7, 9, 14 15, 24, 25, A, B, C, D, E	20%	N:16:15	50 rms	Table land w/ mod. rel.	South 800m.	Lousy Spring

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
N:16:36	N-S 120m. E-W 150m.	N. rim of W. Central Baby Canyon	10, 22, 25D	5%	E. 600m. N:16:28	12 rms	Table land	South 200m.	Bishop Creek
N:16:76, 81, 61, 62, 63, 64, 83, 84, 88, 102	Series	Terraces S. of W. Lousy Canyon	9, 12, 18, 25C, D, E	30%	NW 800m. N:16:15	50 rms	Table land w/ high relief	North 350m.	Lousy Spring
N:16:85	N-S 20m. E-W 20m.	Terraces Bottom of Lousy Canyon	6, 9, 12 20, 24	40%	N. 400m. N:16:96	30 rms	Table land w/ high rel.	North 25m.	Lousy Spring
<u>Linear Borders</u>									
N:16:28	N-S 43m. E-W 96m.	Rim of Central Baby Canyon	12, 18, 29, 25C, D	2%	N:16:28	12 rms	Table land	South 300m.	Bishop Creek
N:16:45	N-S 35m. E-W 96m.	Below S. rim of Baby Canyon	10, 12, 13 18, 21, 22 25C, D	4%	N:16:45	72 rms	Table land w/ mod. rel.	North 200m.	Bishop Creek
N:16:46	N-S 3m. E-W 42m.	S. rim of Cen Baby Canyon	6, 9, 10, 12, 25C	20%	N:16:46	37 rms		North 100m.	Bishop Creek

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
Cleared Land									
N:16:31	N-S 30m. E-W 25m.	N. rim of Cen. Baby Canyon	10, 12, 18 22, 25C, D	2%	W. 650m. N:16:28	12 rms	Table land	South 100m.	Bishop Creek
Flood Plain									
SS #6		Bottom of Lousy Canyon		30%	E. 700m. N:16:86	10 rms		North 50m.	Lousy Spring
N:16:60	N-S 13m. E-W 4.8m.	Mouth of Lousy Canyon	6, 7, 9, 15, 20, 25A, B, C, E	8%	N. 100m. N:16:15	50 rms	Table land w/ con. rel.	South 50m.	Lousy Spring
N:16:66	N-S 35m. E-W 20m.	Terraces, bottom E. Baby Canyon	1, 2, 4, 6, 9, 5, 12, 20, 25C, D	2%	SE 420m. N:16:45	72 rms		North 50m.	Bishop Creek
N:16:67	N-S 22m. E-W 38m.	Bottom of Baby, N. Bishop Cr.	2, 4, 9, 10, 12, 18, 20 25C, D	6%	N. 280m. N:16:28	12 rms		South 25m.	Bishop Creek
N:16:68	N-S 10m. E-W 30m.	Bottom of Baby, N. Bishop Cr.	6, 10, 12, 18, 20, 26, 25, C, D	2%	E. 330m. N:16:46	37 rms.		South 10m.	Bishop Creek
N:16:74	N-S 100m. E-W 300m.	Confluence Bishop Cr. Agua Fria	6, 10, 12, 15, 18, 20, 25C, D	2%	E. 1.4km. N:16:51	18 rms	Table land w/ hg. rel.	North 25m.	Bishop Creek

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
N:16:89	N-S 19m. E-W 34m.	1st terrace mouth of Lousy		15%	E. 1.1km N:16:12	20 rms		North 450m.	Lousy Spring
<u>Check Dam</u>									
N:16:79	N-S 10m. E-W 3m.	W of E end Lousy Canyon		30%	SW N:16:80	60 rms		East 100m.	Lousy Spring
<u>Miscellaneous</u>									
N:16:18	N-S 25m. E-W 8m.	N. rim of E. Larry Canyon	9, 10, 23 25C, D	8%	W 500m. N:16:17	14 rms	Table land w/ con. rel.	South 300m.	Larry Creek
N:16:38		N. rim of West. Baby Canyon	12, 25D	2%	E 800m. N:16:28	12 rms	Table land	South 300m.	Bishop Creek
N:16:39		N. rim of West. Baby Canyon	18, 20. 23, 25C, D	2%	E. 1km. N:16:28	12 rms	Table land	South 200m.	Bishop Creek
Ariz. T:4, Highlands									
<u>Terraces</u>									
U:1:4	L-200m. W-140m.	500m W. of S. end or Robber's Roost	10, 20, 23, 25D	4%	no assoc.		Table land w/ mod. rel.	East 25m.	Hell's Canyon Spring

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
T:4:107	N-S 85m. E-W 100m.	Bottom of Big Spring Canyon	6, 9, 10, 5, 28, 25A, C, D, E, F	15%	no assoc.		Table land w/ hg. rel.	South 80m.	Big Spring
<u>Cleared Land</u>									
T:4:99	N-S 100m. E-W 50m.	E. rim of Hell's Canyon	10, 12, 23, 27, 25D, E	12%	no assoc.		Table land w/ hg. rel.	East 1km.	Hell's Canyon Spring
U:1:2	N-S 35m. E-W 45m.	E. end of New River Mesa	10, 20, 22, 23, 25D, 27	6%	no assoc.		Table land w/ con. rel.	East 1km.	Robber's Roost
<u>Miscellaneous</u>									
T:4:76	N-S 200m. E-W 25m.	W. rim of Wild Burro Mesa, cent.	6, 7, 10, 14, 15, 24, 25A, B, C, D, E	6%	no assoc.		Open low mnt's.	NE 800m.	Agua Fria
			Ariz. T:4, Lowlands						
<u>Linear Borders</u>									
T:4:54	N-S 30m. E-W 100m	N. of T:4:8, 400m.	7, 8, 9, 14, 20, 25A, E	2%	SW 400m T:4:8	70 rms	Open low mnt's	East 200m	Cline Creek

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
T:4:54B	N-S 100m. E-W 30m.	N. of T:4:8 400m.	7, 8, 9, 14, 20, 25A, 25A, E	2%	SW 400m. T:4:8	70 rms	Open low mnt's	East 200m	Cline Creek
T:4:6	N-S 50m E-W 30m. N-S 18m. E-W 130m N-S 35m. E-W 200m.	2km S of T:4:5	7, 8, 12, 25B, E	20%	T:4:6	30 rms	Open high hills	North 500m.	Fig Spring
T:4:105	N-S 110m. E-W 90m.	200m. SW Quail Spring	7, 8, 12, 25B, E	3%	E 250m.	70 rms.	Open Low Hills	NE 200m.	Quail Spring
<u>Terraces</u>									
T:4:6	N-S 350m. E-W 60m.	2km S. of T:4:5	7, 8, 12, 25B, E	20%	T:4:6	30 rms	Open High Hills	North 500m.	Fig Spring
T:4:39	N-S 210m. E-W 100m.	2km N. of T:4:5		10%	SW 1km T:4:42	50 rms	Open Low mts.	South 300m.	New River
T:4:42	N-S 150m. E-W 40m.	1km NW of T:4:5	6, 7, 8, 9 12, 14, 15, 24, 25A, C, D, E	2%	T:4:42	50 rms	Open Low mts.	East 25m.	Cline Creek

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
T:4:45	L-170m. W-170m.	2km. S. of T:4:8	6, 7, 8, 9, 12, 14, 25A, B, D, E	1%	N 1.7km. T:4:8	70 rms.	Open Low Mts.	West 10m.	Cline Creek
T:4:47	N-S 250m. E-W 50m.	1km NW of T:4:5	7, 8, 9, 12 14, 25A, B, D, E	3%	E 600m T:4:42	50 rms	Open Low Mts.	North 250m.	New River
T:4:48A	N-S 100m. E-W 50m.	1km. E of T:4:8	7, 8, 9, 14, 20, 25A E	3%	W 700m. T:4:8	70 rms	Open Low Mts.	East 25m.	Cline Creek
T:4:53	N-S 38m. E-W 9m.	459m. E T:4:8	7, 8, 9, 14 16, 24, 25A, B	5%	W 460m. T:4:8	70 rms	Open Low Mts.	East 150m.	Cline Creek
T:4:57	N-S 90m. E-W 40m.	450m. NE T:4:7	6, 7, 8, 9, 12, 14, 25D, E	10%	W 2.75km. T:4:8	70 rms	Open Low Mts.	East 300m.	Cline Creek
T:4:58	N-S 129m. E-W 50m.	1km NE of T:4:7	6, 7, 14, 25A, C, E	2%	W 3.5km T:4:8	70 rms	Open Low Mts.	East 150m.	Cline Creek
T:4:63	N-S E-W 70m.	1.2km. N T:4:8		3%	S 1.1km T:4:8	70 rms	Open Low Mts.	West 75m.	Skunk Creek
T:4:64	N-S 50m. E-W 40m.	1.2km NE T:4:8	7, 9, 14, 18, 25A, B, C, D, E	2%	SW 1.4km T:4:8	70 rms	Open Low Mts.	West 40m.	Cline Creek

TABLE 3-VI -- Continued

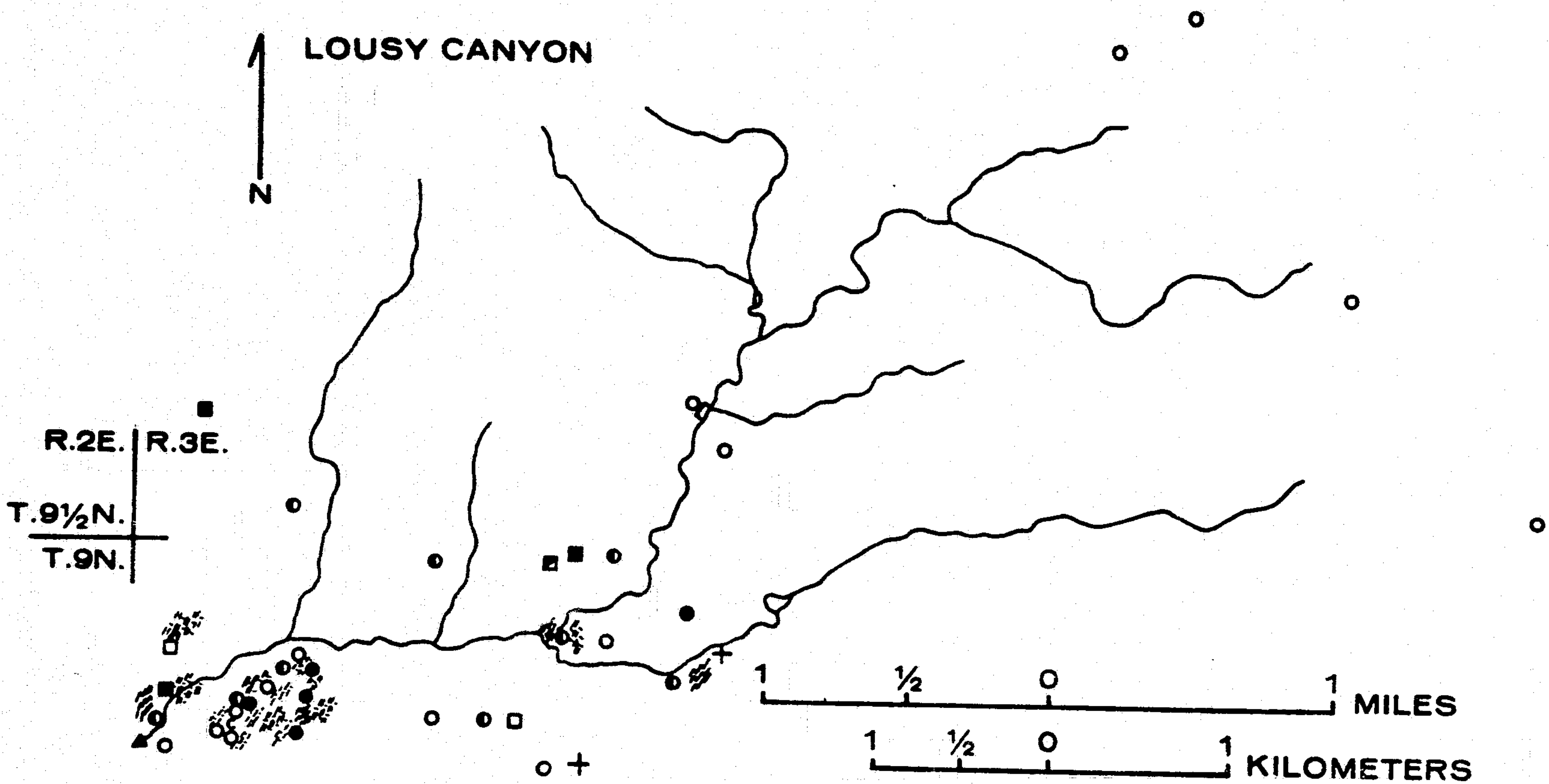
Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
T:4:66	N-S 150m. E-W 40m.	1.1km N Quail Spring	7, 9, 14, 24, 25A,	2%	SW 800m. T:4:8	70 rms	Open Low Mts.	West 80m.	Cline Creek
T:4:69	N-S 25m. E-W 12m.	700m. NE Quail Spring		2%	W 1km. T:4:8	70 rms		East 150m.	Cline Creek
T:4:71	N-S 100m. E-W 50m.	1km. E T:4:8		2%	W 1.45km. T:4:8	70 rms	Open Low Mts.	East 10m.	Cline Creek
T:4:74	N-S 25m. E-W 65m.	300m. N Cline Well	7, 25A, D, E	2%	NW 2km T:4:8	70 rms	Open Low Mts.	North 280m	Cline Creek
T:4:90	N-S 120m. E-W 50m.	800m E Cline Well	7, 24A, B, C, E, 14	4%	NW 2.7km T:4:8	70rm rms	Open Low Mts.	West 50m.	Cline Creek
Flood Plain									
T:4:31	N-S 140m. E-W 143m.	2km. NE T:4:5	6, 7, 8, 9, 14, 25A, C, E	10%	SW 1.5km T:4:42	50 rms	Open High Mts.	North 100m. North 100m.	New River
T:4:35	N-S 25m. E-W 16m.	2km. S T:4:8	7, 8, 11, 14, 20, 25B, C, D, E	2%	N 1.9km T:4:8	70 rms	Open Low Mts.	N & S 25m.	Cline Creek
T:4:38	N-S 20m. E-W 25m.	N 2km. T:4:5	14, 25E	3%	S 550m. T:4:42	50 rms	Open Low Mts.	South 20m.	New River

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
T:4:43	Diam. 25m.	1km S T:4:8	7, 8, 14, 15, 25C, D, E	1%	S 700m T:4:8	70 rms	Open Low Mts.	East 200m.	Cline Creek
T:4:46	N-S 10m E-W 10m.	2km. NW T:4:5	6, 7, 8, 9, 12, 14, 25, D, E	1%	S 700m. T:4:8	70 rms	Open Low Mts.	South 300m.	New River
T:4:52	N-S 25m. E-W 25m.	2km W T:4:7	7, 14, 15 17, 25C	1%	NW 920m. T:4:8	70 rms	Open Low Mts.	West 50m.	Cline Creek
T:4:56	N-S 60m. E-W 147m.	500m. N T:4:7	7, 8, 14, 25E	4%	W 2.9km T:4:8	70 rms	Open Low Mts.	West 100m.	Cline Creek
T:4:89	N-S 40m. E-W 40m.	500m SE T:4:7	6, 7, 8, 20, 25A, C, D, E				Open Low Mts.		
<u>Check Dams</u>									
T:4:50	N-S 15m. E-W 50m.	1km NE T:4:8	7, 8, 14, 25A, D, E	1%	SW 1km T:4:8	70 rms	Open Low Mts.	East 70m.	Cline Creek
T:4:82	N-S 30m. E-W 25m.	750m. S T:4:7	7, 8, 14, 25A, B, C, D, E	1%	NW 2.6km T:4:8	70 rms	Open Low Mts.	West 50m.	Cline Creek
T:4:83	N-S 50m. E-W 45m.	750m. S T:4:7	6, 7, 8, 9, 14, 24, 25, A, E	2%	NW 2.8km. T:4:8	70 rms	Open Low Mts.	East 2m.	Cline Creek

TABLE 3-VI -- Continued

Site	Recorded Extent of System	Location	Vegetation	Approx. Slope	Nearest Site	Size	Land Form	Distance and Direction to Nearest H_2O	Stream
Miscellaneous									
T:4:65	N-S 300m. E-W 60m.	100m. SW Cline Well	6, 7, 8, 12, 14, 25A, B, D, E	1%	N 2.4km. T:4:8	70 rms	Open Low Mts.	North 100m	Cline Creek
			Lower Sonoran T:3						
Canals									
T:3:46	N-S 350m. E-W 325m.		6, 7, 14, 20, 25A, D, E, F	2%			Open Low Mts.		
Waffle Garden									
T:3:4			6, 8, 14, 25A	1%					



pp Figure 3-11a. LOUSY CANYON SURVEYED SITES AND SYSTEMS.

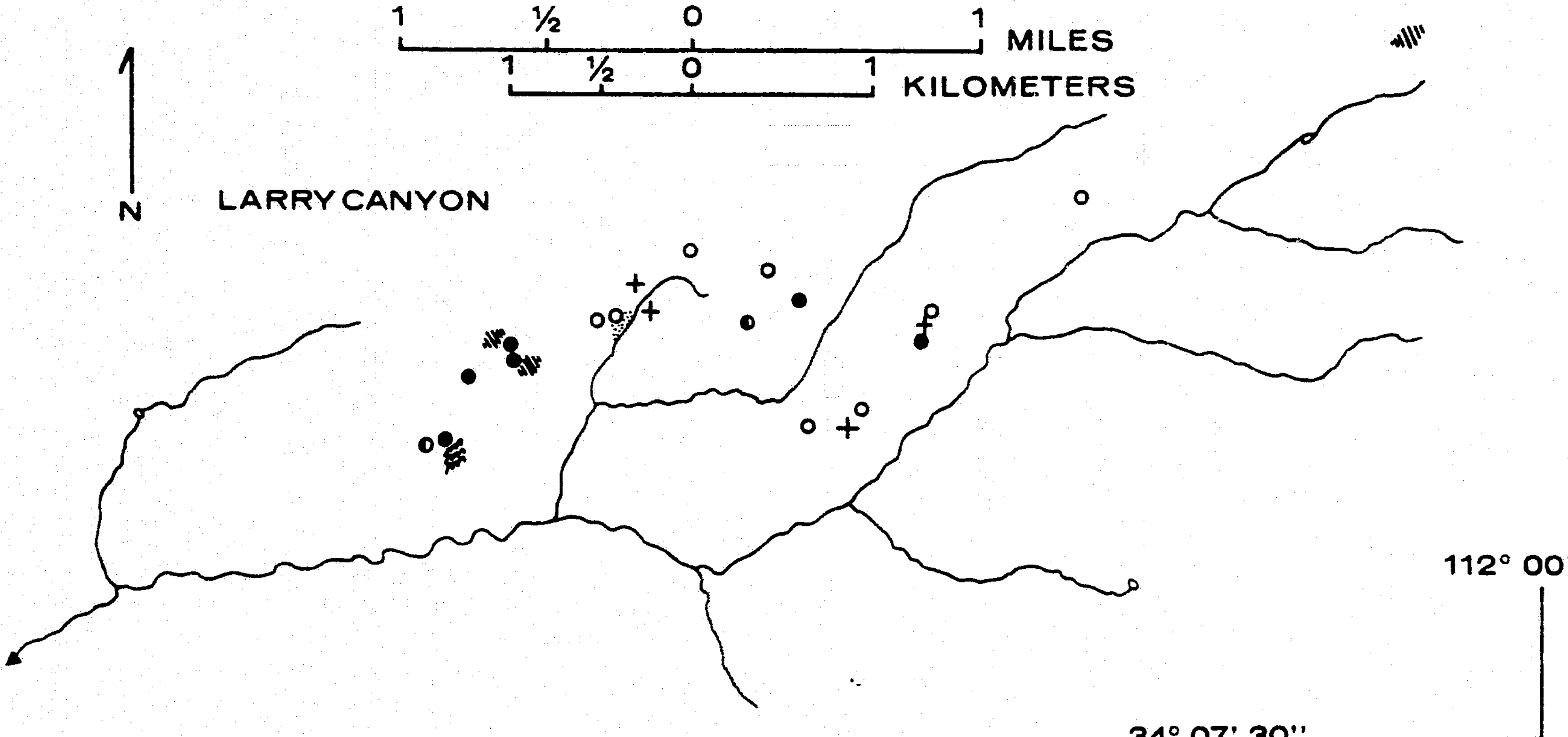


Figure 3-11b. LARRY CANYON SURVEYED SITES AND SYSTEMS.

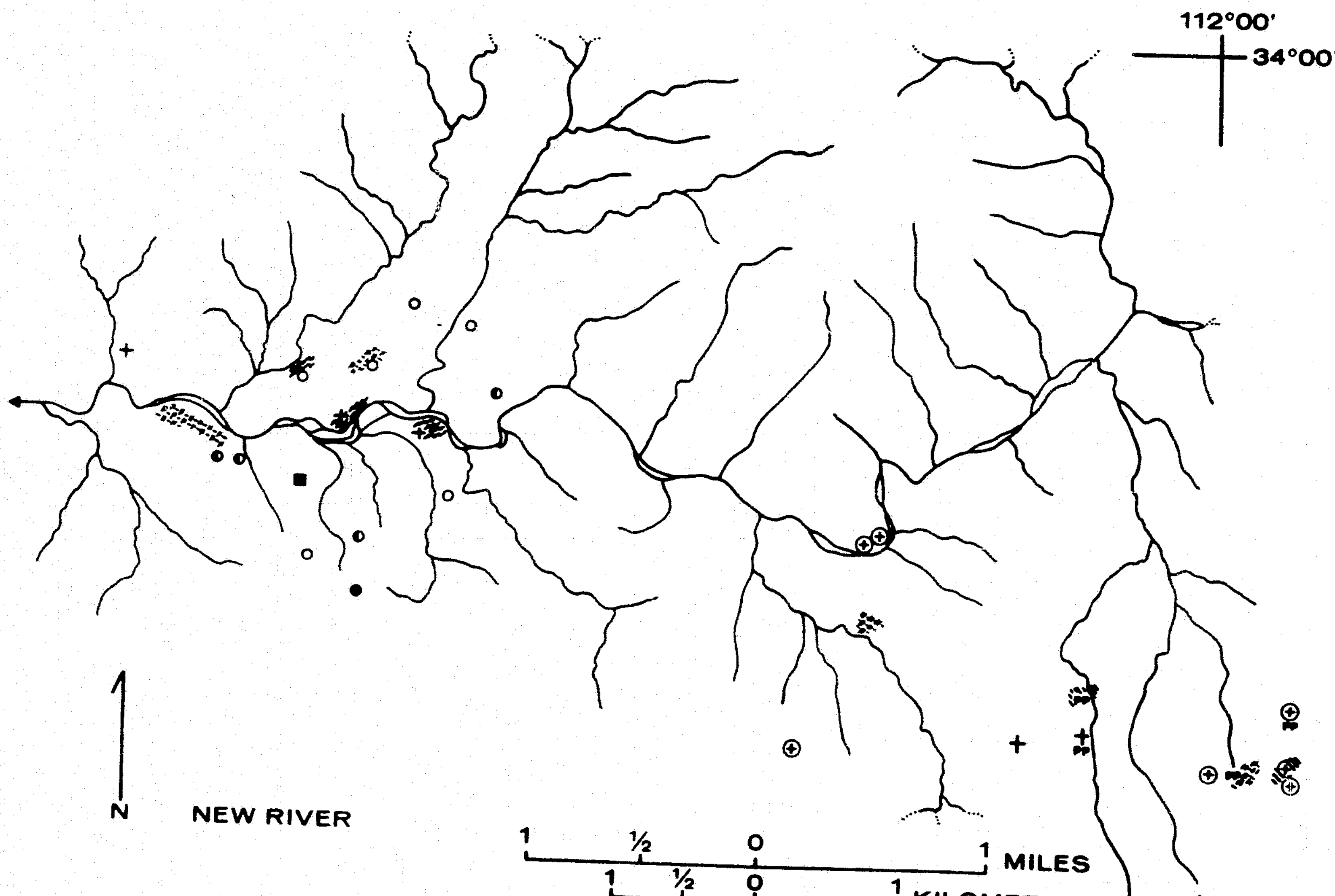


Figure 3-11c. NEW RIVER DRAINAGE SURVEYED SITES AND SYSTEMS

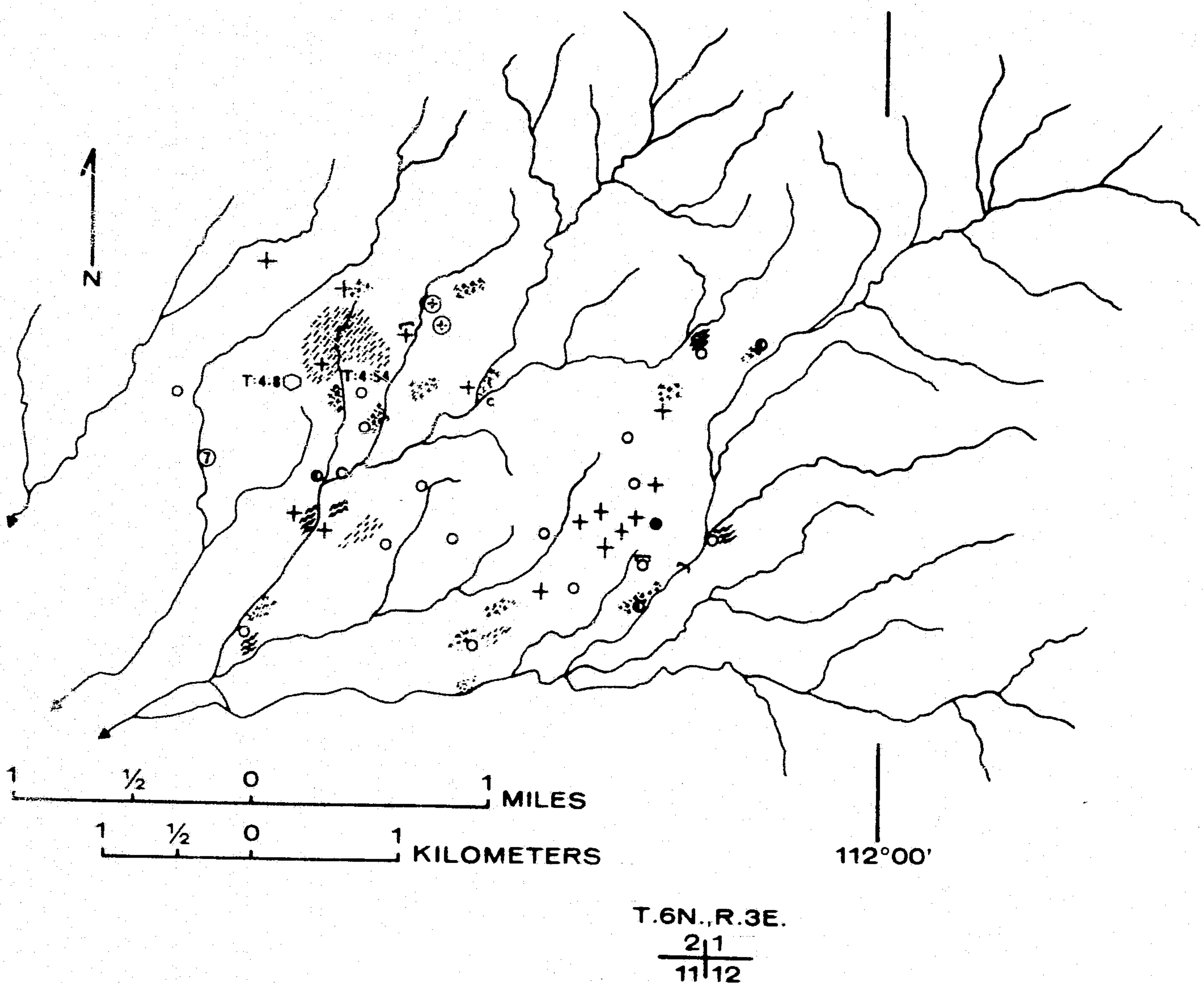


Figure 3-11d. AREA NEAR ARIZ T:4:8 SURVEYED SITES AND SYSTEMS

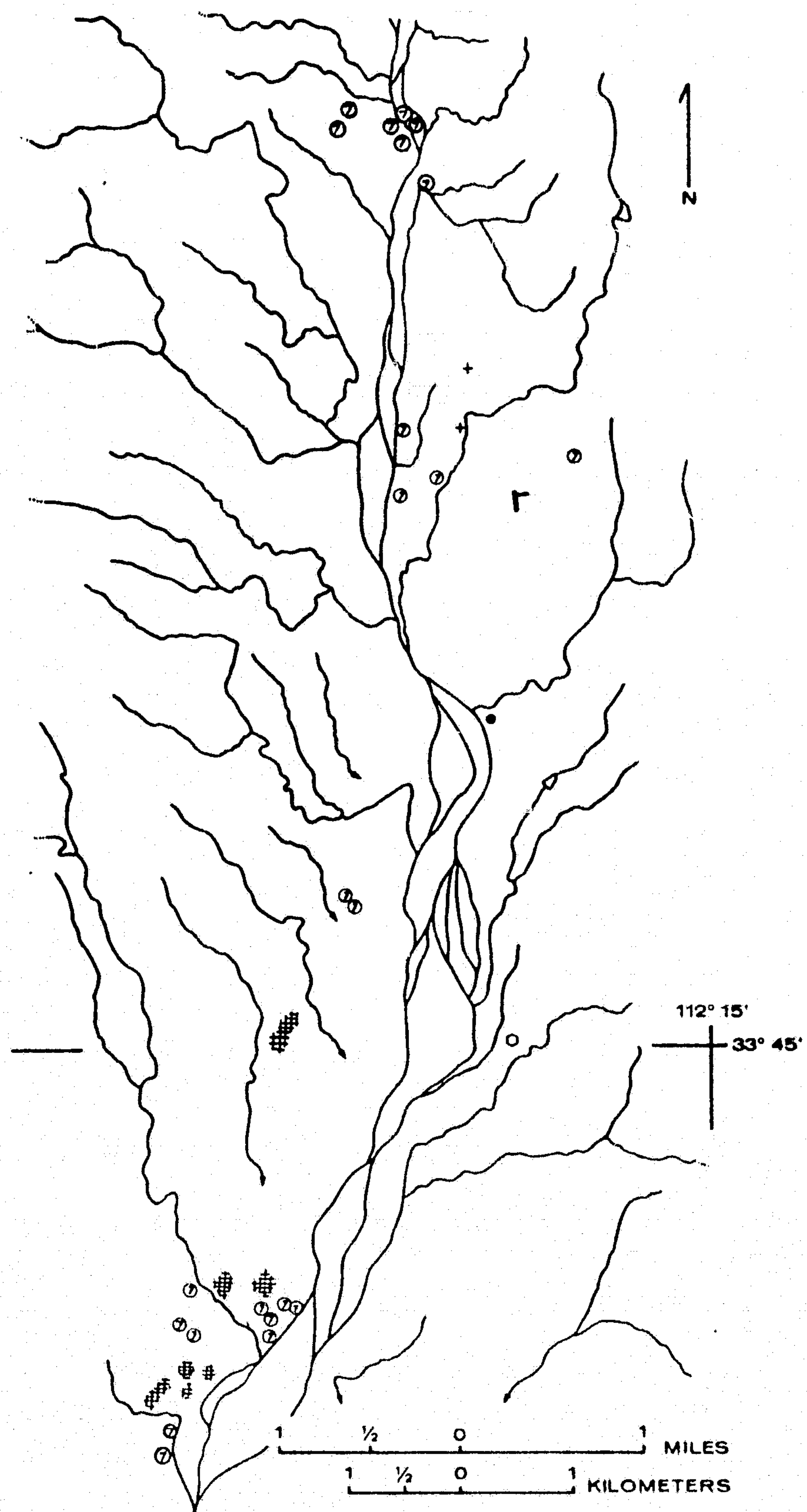


Figure 3-11e. LOWER AGUA - CALDWOOD BUTTE AREA SURVEYED SYSTEMS.

TABLE 3-VII

IMAGE FORMAT EVALUATION

Tonal Quality		Symmetrical Disturbances					
Natural Terraces Apparent	Black Canyon City Mappable	Shadows Conflict	Smallest Feature Defined	Format Type	Resolution	Magnification*	Slope Determinable
Only in Transition Zone	No	Yes	$150m^2$	B/W S190A	Poor to Good	10	Only on South Facing Slopes
In all Areas	No	Yes	$150m^2$	HR Color S190A	Good	12	Only on South Facing Slopes
In all Areas	Yes, But Buildings Ill-defined	Yes, But to a Lesser Degree	$200m^2$	Color IR S190A	Good	10	Only on South Facing Slopes
In All Areas	Yes	No	$50m^2$	HR Color S190B	Good to Excellent	15 to 20	Both North & South Facing Slopes
In All Areas	Yes	No, But With Qualifications	$50m^2$	Color IR S190B	Excellent	15 to 20	Both North & South Facing Slopes
In All Areas	Yes, But Buildings & Some Sts. Not Defined	Yes, But to a Lesser Degree	$100m^2$	B/W U-2	Good to Excellent	12	Good for all Topographic Feat in All Direction
Inadequate Because of small aerial coverage	No Information	No	5 x 7m	B/W Fixed-Wing Low Altitude	Excellent	15	

*To what degree power picture is clear.

altitude imagery, was restricted almost exclusively to the Upper Sonoran mesa/canyon complex. Throughout this region the sloping canyon walls lent themselves to minimal modification by the ancient inhabitants. Natural terraces were enhanced and artificial ones created, though only on a limited scale. The early morning, and mid-afternoon shadows aided in the identification of the terraces, which appeared as parallel linear alignments. However, this key is very tenuous at best because of the absolute necessity for proper timing on the part of the photographic mission, and the very small number of terraces identified in this manner.

In conclusion, the identification of water management systems from aerial imagery proved only slightly more successful than the identification of site locations. The season and time of day during which most of the coverage was taken, and the nature of the systems themselves were all factors which combined to obscure any definitive identification of the systems without intensive ground truth operations.

3.4.3 Applications of Imagery to Archaeology Analysis

Introduction

As has been noted in various sections of this report, not all imagery formats nor all manned Skylab missions were

amenable to interpretation and evaluation. The SL2 imagery was obscured by cloud cover and the SL3 coverage missed the test area. The S192 multispectual scanner could not be evaluated for any mission due to the inaccessibility of necessary enhancement techniques. Therefore, all Skylab data discussed in this section are from the final manned mission (SL4) in both the S190A and S190B formats.

Although this project was heavily weighted towards consideration of questions of archaeological import, the investigators had, even initially, anticipated that the benefits of orbital photographic coverage as regards archaeological site <u>discovery</u>, would be minimal. It was felt then, as now, that the problems resulting from the resolution of the various formats in terms of ground area would be great. Parenthetically, it should be noted that the resolution on the various sets, particularly the S190B, was very impressive although even in that case the discovery of archaeological sites could only rarely (and with prior knowledge of a given sub-area) be accomplished.

Although site discovery capabilities were minimal, it was possible to <u>predict</u> the general, and often specific, location of archaeological sites and water management/land utilization systems from the imagery. For lack of a better term we have labeled this process the "site predictability factor."

It can be accomplished with minimal prior knowledge of a study area, taking into consideration such characteristics as slope, hydrological situation, and land form, all of which are conditions which could be determined from the imagery. This "site predictability factor" ultimately resulted in the establishment of several key indicators which aided in the interpretation of the photographic coverage.

Early in the analysis of the various imagery formats it was apparent that lower altitude coverage, such as U-2 overflights and light aircraft photoreconnaissance should supply more usable data on an archaeological basis (particularly as regards site and/or system discovery) than the Skylab imagery. The same basis keying system utilized in the interpretation of Skylab imagery was also employed in the analysis of the lower altitude data (Table 3-VII). In essence these keys represent subjective criteria which were determined to be useful indicators of archaeological site/system localities. They include factors such as slope, tonal variation and symmetrical disturbance. As a point of clarification, althouth the low altitude coverage supplied data adequate for mapping individual archaeological sites and systems, the Skylab imagery proved more important in the establishment of a comprehensive data base which could be utilized for the prediction of potential localities of prehistoric water management and/or land utilization.

One final introductory note. Analysis of the various formats was carried out at three levels. Initially the imagery was visually evaluated in the 9" x 9" format without the aid of magnification devices. Stereo pairs were then examined using a relatively simple binocular stereoscope. Finally all formats with the exception of the low altitude fixed wing photo reconnaissance which had no stereo pairs, were analyzed, evaluated, and interpreted through the use of the Bausch and Lomb Zoom Stereoscope.

Comparison of Photographic Formats

In comparing photographic coverage of the test area in terms of utility to the assessment of the archaeological questions being investigated, two major distinguishing criteria were utilized. The first, and perhaps most important, is altitude. In our analysis and interpretation imagery from three different altitudes were utilized. These included the Skylab satellite coverage, in particular selected formats of S190A and S190B from the Skylab 4 mission, average orbital distance 235 miles; medium altitude (approximately 65,000 feet) U-2 coverage from overflights over the test area (stereoscopic pairs in black and white prints); and low altitude, 2-4000 feet, black and white coverage of selected portions of the test area.

The second major criteria was by format. No color or color infrared imagery other than that from the satellite coverage was available for evaluation. Black and white coverage of S190A was evaluated but black and white coverage from S190B was not available. High resolution color and color infrared formats from both S190A and S190B were analyzed and compared. The remainder of this section details the formats which were compared, beginning with the low altitude coverage.

The majority of our imagery from low altitude overflights derived from coverage obtained during the fall of 1971 and the spring of 1973. They were taken by the United States Geological Survey in conjunction with a hydrological study of the middle to lower Agua Fria drainage. These photographs were taken from an altitude not exceeding 7000 feet above the ground surface. Additional low altitude imagery was taken from both fixed-wing aircraft and helicopters during the ground truth activities of the project and were most generally coverage of specific site localities.

The low altitude coverage proved more than adequate for mapping of major sites (Figure A-10, for example was originally drafted through use of low altitude imagery). Nonetheless aerial coverage provided by available low altitude imagery was greatly restricted, thereby severely limiting the value of the imagery in a comparative analysis situation. Low altitude

imagery was further restricted to only one format thereby precluding any comparisons along those lines.

The low altitude imagery allowed for the delineation of some small plant communities (chain fruit cholla forests, for example) and in some cases identification of individual species members. The latter was primarily true of larger species such as saguaro and palo verde and other trees. It further allowed the analyst to identify the ubiquitous small drainage networks in the transition zone of the study area. It was the assessment of those analyzing the various sets of imagery that coverage from a similar altitude which utilized a high resolution color format in a greater areal extent would have proven more valuable, especially in the determination of specific plant community types. For the archaeologist the black and white format was useful. The value of a color format is minimized archaeologically, although low altitude coverages of sites have proven to be of importance in the definition and recording of trash areas and other disturbed sections of sites. For the archaeologist, perhaps the most useful format is one utilizing infrared (either black and white or color). It has been suggested in two studies (Gumerman and Lyons 1971, Gumerman and Neely 1972) that cultural features often are most easily and clearly defined when a color infrared format is utilized.

During the analysis of all formats several selected areas of the study area were concentrated upon, insuring a sound and common comparative basis for which to evaluate the relative merits of each. These areas of concentration included Perry Mesa in the Mesa-Canyon complex; Black Canyon City, New River Mesa, the area near Ariz. T:4:8, the Agua Fria River between Lake Pleasant on the South and Black Canyon City on the North, all in the transition zone; and the Calderwood Butte-Lower Agua Fria area south of Lake Pleasant in the Basin and Range Province.

The U-2 imagery, taken specifically for mapping purposes, supplied stereoscopic coverage of the entire test area. Of all formats examined it illustrated most dramatically the inadequate nature of black and white formats for purposes of mapping structural units and cultural features.

While most topographic features, including drainage networks, were easily discernible on the U-2 coverage, areas of urban development (both on the northern fringes of the Phoenix Metropolitan area and Black Canyon City) as well as those with known archaeological sites of significant size were extremely difficult to define. The black and white format to which we were restricted afforded very little contrast in terms of the key archaeological indicators of tonal change and symmetrical disturbance. Although gross differences in tone

were sufficient to easily indicate such features as mountains, drainages, some basic geologic units and differentiation in the density of plant cover, the tonal quality of the imagery did not allow for the definition of lesser tonal changes. In a similar manner the U-2 imagery was inadequate for delineating the symmetrical disturbances of the ground surface often associated with archaeological sites. Had the definition of minor tonal changes and symmetrical disturbances been possible, the archaeologists were of the opinion that the road patterns in Black Canyon City and the large site north of Perry Tank Canyon in the middle of the Mesa-Canyon complex would have been fairly easily discernible. They were not. Archaeologists concluded that of all the formats analyzed, the U-2 proved to be the least useful and most inadequate for our purposes of either site/system discovery or predictability.

Due to difficulties encountered in our analysis of the U-2 imagery, in particular our inability to utilize two of the three key indicators considered significant for prediction of archaeological sites and systems, it was reasoned that these keys would need modification to be useful in the analysis of the various Skylab formats. This reasoning proved premature and generally fallacious. This was particularly the case in the analysis of available S190 coverage, both in the high resolution color and color infrared formats. In both cases

the key indicators performed at originally expected levels. Further, it was almost immediately apparent that imagery from the Earth Terrain Camera was the best of any of the high altitude imagery supplied for the kinds of evaluation and interpretation required for archaeological considerations. The S190A imagery lacked the resolution qualities of the S190B data, became grainy under magnification exceeding twelve power, and did not show in either black and white or color formats necessary tonal quality. We were likewise less than successful in determining slope angle on the S190A imagery.

As noted in Table 3-7 features such as New River Mesa and the canyon systems dissecting Perry Mesa were distinct in all formats. However, only in the S190B format could individual streets, buildings and agricultural fields in or near the community of Black Canyon City be defined with any assurance. It should be noted that only the S190B imagery afforded the opportunity for the investigating archaeologists to define smaller areas of disturbance such as earthenwork cattle tanks. None of the satellite coverage allowed for the identification or definition of specific arcaheological sites as such. For example, on all sets of orbital coverage analyzed (S190A and S190B) the hill upon which the site Ariz. T:4:8 was situated could be distinguished. However, on no format could the investigators actually see any of the structures or other cultural

features which would have indicated the presence of a large habitation site.

Offsetting this negative aspect of the analysis was the ability, most notably in the S190B color infrared coverage, of the investigators to easily denote localities containing dense riparian vegetation. Through definition of localities of potentially high water accessibility throughout the study area, the "site predictability factor" came into play, as the archaeologists could state with some confidence that both sites and water management/land utilization systems were more likely to be found in areas near such accessible water sources. In the ideal situation (one in which photo interpretation preceded ground truth activities) it would have then been possible for the project team archaeologists to structure survey transects in such a way as to take into consideration localities of potentially high water accessibility as opposed to those areas characterized by potentially lower water accessibility.

Perhaps the major problem encountered in the analysis of all types of Skylab coverage was the time of day at which the imagery was taken (ca. 5 o'clock P.M.). The effect of the late afternoon shadows was to prohibit any possibility of viewing the bottoms of the deeper canyons dissecting Perry Mesa (especially Lousy and Larry Canyons) thereby eliminating

the potential comparison of mesa-top and canyon bottom floral communities. An additional effect of the shadows was to prohibit prediction of site/system localities occurring on the natural terraces near the confluence of these canyon systems and the Agua Fria drainage. Further, the shadow effect increased our inability to explicitly identify any of the larger hill-top masonry sites (including Ariz. T:4:8), as the shadows substantially distorted the symmetrical outlines of the various archaeological features.

Without question the least effective of the Skylab formats was the S190A black and white. This can be most reasonably attributed to two factors: 1) the grainy nature of the imagery under magnification of higher than ten (10) power, and 2) the shadowing effects which were more readily apparent in the various gray tones of the black and white format. By comparison the color formats, both high resolution color and color infrared were much more informative, given our three key archaeological indicators. In particular the minute tonal changes were much more obvious, especially in the case of the S190B coverage.

Archaeologists were particularly impressed with the resolution capabilities of the S190B color formats. In our opinion the potential of this format in future archaeological studies is excellent, especially in definition and mapping of

localities of riparian vegetation. As a next logical step we would suggest that it might prove instructive for archaeologists to utilize this format (S190B) for viewing such high density prehistoric population centers as Teotihuacan in Mexico. This would enable investigators to more fully define the parameters of our key indicators for utilization in mapping these and other types of prehistoric urban centers. The tonal changes appear to be of such subtlety as to allow for the easy identification of symmetrical disturbance, even when the effects of vegetation ground cover is taken into account.

Explanation of Keys

The satellite coverage of the study area proved adequate for the determination of slope and related topographic features. Through consideration of the time of day during which the coverage was taken and thereby the determination of the length of shadowing effects, slope angles and heights of various features could be calculated.

Although only limited analysis of this type was actually conducted, given time and equipment restraints, we feel the potential use of such information could be great. Ground truth activities had shown that the majority of water management/land utilization systems occurred within a restricted slope range of two (2) to twenty (20) percent. The test area, enveloping

considerable regions of significant dissection could, then, be broken down into areas of potential utilization based solely on slope information. The "site predictability factor" became important in this phase of analysis as those areas which could be selected as potential areas of hydroagricultural system concentrations were repeatedly coincidental with those areas of known concentration which had been derived from previously accomplished ground truth reconnaissance. In the ideal situation (in which photo analysis and interpretation precedes ground truth activities) a careful examination of the high altitude coverage could hypothetically have supplied insight into potential utilization locales and survey strategies could have then been derived to cover those areas. As noted in Table 3-VII the best imagery for the derivation of this type of data was the S190B high resolution color, and not the lower altitude U-2 coverage. In large measure this was a result of the synoptic factor achieved in the Skylab coverage which allowed for the formulation of a more comprehensive picture of any given area.

It was apparent early in the analysis of the Skylab imagery that the criteria set forth for the interpretation of photographic reconnaissance data would only partially answer the multitudinous questions being asked by the archaeologists. The interpretation of aerial photographs by archaeologists has

been a sporadic but ongoing endeavor since World War I (Deuel 1969), yet in most instances the data has been derived from low altitude coverage, usually taken from fixed-wing aircraft. Those criteria suggested for the analysis of such photographs, i.e., "climate, season, time of day, intensity and direction of light, composition of soil, nature of plant growth, the plane's altitude and camera angle for obliques . . ." (Deuel 1969:266), could not all be taken into direct consideration in the evaluation of the satellite coverage being utilized in this project. For example, the nature of the plant cover over the majority of the study area could not be fully determined on any of the high altitude imagery supplied (see above - Biological Photo Interpretation). However, the intensity and direction of light when added to information supplied on the time of day at which coverage was taken did provide data sets which gave input to the second of the important key indicators, tonal change. Differing tonal qualities, most especially in the color formats, not only indicated soil composition and bedrock differences, but also supplied clues as to the presence of soil disturbances and the presence of the third key indicator, symmetrical disturbance patterns.

The tonal quality of both the S190A and S190B coverage was good, although the latter, because of better resolution, enabled the investigators to identify some tonal differences

which were difficult or impossible to discern on the S190A imagery. Such modern man-made features as roads, watering tanks, parking lots, cleared agricultural fields and individual buildings were discernible as lighter patches of a regular outline. Various color changes were noted on those formats and were indicative of such phenomena as denser riparian growth and fields under cultivation. The symmetrical disturbances created by such man-made features led to the conclusion that through careful examination of the photographs the larger habitation sites in the test area, which in some cases cover upwards of ten (10) acres (4 hectares), could be identified. Of the various sites which could have been selected, the ultimate choice was an above ground puebloan site of significant size (200+ rooms) located on the north rim of Perry Tank Canyon on Perry Mesa. This site was searched for on each set of high altitude imagery. In all cases except the high resolution color S190B, this site could not be identified. On the high resolution color S190B the tonal change in the area of question indicated some type of unspecified disturbance. However, the normal indication of a man-made feature, that of symmetrical outline, could not be specifically identified, probably for two reasons: 1) the overgrowth of vegetation in the area which has occurred since the establishment and subsequent abandonment of the site, and 2) the presence in the immediate vicinity of

the site of more recent disturbance, principally power line haul roads and rancher access roads, which tended to confuse the overall impression of the site outline.

Despite these problems, it is our opinion that the utilization of tonal differences and symmetrical disturbances as keys for the interpretation of Skylab imagery as regards archaeological materials is important. The fact that individual features in the modern community of Black Canyon City (approximate areal extent of four square miles) could be readily identified coupled with the observation that this community could have been mapped accurately from the photographs tends to illustrate and reinforce the potential use of orbital coverage in the definition and mapping of high population density archaeological zones such as Chaco Canyon (New Mexico) and Teotihuacan in the Valley of Mexico.

3.4.4 Summary of Archaeology Results

The analysis of Skylab imagery was, for the most part, conducted after ground activities had occurred. In this case project team archaeologists were already familiar with many areas of archaeological import within the study region. Due to this factor, photo analysis tended to concentrate on known localities of archaeological sites or water management/land utilization systems. It was apparent early in the analyses

TABLE 3-VIII

IMAGE USEFULNESS EVALUATION

Features Studied	S 190 A Black & White	S 190 A Color	S 190 A Infrared	S 190 B Enhanced Color	S 190 B Color	S 190 B Infrared	U-2	Low Level
I. Topographical								
A. Man-made								
1. Habitation	Poor	Fair	P	Good	G	G	Very Good	VG
2. Roadways	P	F P	P	G	VG	G	VG	VG
B. Natural								
1. Drainageways								
a. Major	F	VG	G	VG	VG	VG	VG	VG
b. Minor	P	VG	G	G	VG	VG	VG	VG
2. Plains & Bajadas	G	VG	G	G	VG	VG	VG	VG
3. Hills, Buttes, Mesas	G	VG	G	G	VG	VG	VG	VG
4. Mountains	G	VG	G	G	VG	VG	VG	VG
II. Vegetational								
A. Regional								
1. Vegetation Types	P	P	P	P	P	F	F	G
2. General Density Patterns								
a. Riparian	P	P	P	P	F	G	VG	VG
b. Non-riparian	F	F	F	F	F	G	VG	VG
B. Local								
1. Differences in Vegetation densities on slopes of different exposures	F[1]	F[1]	F[1]	F	F	G-F[2]	G	VG
2. Differences in vegetation densities on lower vs. higher portions of slopes above larger drainages	F	F	F	F	F	G-F[2]	P	VG
3. Differences in vegetation densities in drainage channels vs. adjacent slopes	P	P	P	P	F-P[2]	G-F[2]	G-F[2]	VG
4. Width of riparian vegetation zones in major drainages	P	F	P	P	F	G	VG	VG
C. Agricultural	P	P	F	P	G	VG	G	VG
General Rating								
Topography	F	G	F	G	VG	VG	VG	VG
Vegetation	P	P	P	P	F	G	G	VG

[1]Difficulties due to shadows.

[2]Some areas better than others.

that with the exception of the admittedly spotty low altitude coverage, little direct data of an archaeological nature could be derived from the imagery. However, the ancillary information provided by both S190A and S190B imagery (most notably the latter), and to a lesser extent the U-2 overflights aided in the definition of the topographic nature of the test area, the delineation of drainage networks, the presence or absence of available ground water, and accessibility of any given area for ground truth reconnaissance.

These data made it easier for the archaeologists to discern potential areas of prehistoric utilization. In turn the geological mapping of the test area proceeded with some confidence and could have led, if the imagery had been analyzed prior to ground truth activities, to the establishment of survey transects representative of the wide range of topographic variability within the study area.

Despite the many unforeseen problems which seemingly plagued this project since its inception, archaeologists for the first time utilized orbital photographic reconnaissance data and were able to suggest that it represents a potentially valuable source of information for investigators interested in identifying and defining the nature of prehistoric, and by extrapolation, contemporary patterns of land utilization and water management. The potential in future archaeological work

for the formulation of well-defined hypotheses based in part upon orbital reconnaissance of a given area should be easily recognizable. Investigators can easily define the possibilities of encountering, for example, water management/land utilization systems through a careful examination of such factors as slope angle and tonal change, both of which are available from orbital coverage of the S190 series, particularly S190B.

4.0 PROJECT RESULTS

The individual discipline results, although significant in their own right, need to be integrated in order to properly reconstruct the environmental setting and probable adaptation of the prehistoric population to the test area. The principal project goal was the definition of the prehistoric land use and water management systems. In order to successfully accomplish that task, an examination of the present environmental setting was undertaken. Each of the supporting disciplines supplied data which provided a reconstruction of the general environment of the test area during the postulated times of primary occupation. It was also possible to postulate adaptive strategies employed by the populations, drawing principally from the remnant hydroagricultural systems.

4.1 ENVIRONMENTAL SETTING

Analysis and Interpretation-Adaption of Pre-Columbian Man to Local Conditions

The research in central Arizona has generated many more questions than we are currently capable of answering, especially those questions regarding the archaeological situation. The four major problems confronting the project team in the

analysis and interpretive aspects of the work are:

1) Temporal placement of sites and agricultural systems,
2) Reconstructing past environmental conditions, particularly between AD 1000 and AD 1450,
3) Associating specific sites with specific water management/land use systems,
4) Assessing the interrelationships, if any, among sites within and between the three major subdivisions of the study area.

4.1.1. Temporal Placement

To accurately and specifically assess the processes of prehistoric adaptations and possible changes therein archaeologists need accurate temporal control of their data. As a result of our preliminary field studies both on the ground and from light aircraft, project team archaeologists had hypothesized, in fact predicted, a long temporal span of prehistoric exploitation, most notably in the transition zone. Present information does not negate this possibility, but neither is it highly supportive. In fact we do not have the temporal control necessary to make explicit statements concerning the span of occupation.

Most dating techniques employed by Southwestern archaelo-

gists were either unavailable to us or of such an incomplete nature that substantive statements either could not be made or could be made only as educated guesses. These traditional techniques include dendrochronology (tree-ring dating), carbon-14 and cross dating by means of decorated ceramics.

1) Tree rings -- no datable species of tree were recovered during our test excavations, so use of this excellent means of dating was eliminated.

2) Carbon-14 -- Our test excavations in 1973-74 uncovered no charcoal samples amenable for dating. Only a few samples were recovered during fieldwork in the spring of 1975. Although submitted, the results of the analyses have not yet been made available to us.

3) Cross dating through use of decorated ceramics -- Utilizing decorated ceramics as a dating technique is, generally speaking, a key indicator of the relative temporal placements of a site or sites. In central Arizona, however, the percentage of decorated pottery recovered during our fieldwork constitutes less than 1% of the total ceramic assemblage. In addition, the majority of decorated pottery recovered was restricted in distribution to the Upper Sonoran Mesa-Canyon complex.

TABLE 4-I

HYDRATION CORRELATION CHART

Site	Provenience	No. Spec.	Obsidian Date	No. Spec.	Ceramic Type	Date
Ariz. N:16:51	Room 5, Sec. A Fill	1	A.D. 1205	1	Tusayan B/W	1225-1300
	99cm. below datum	1	1338	1	Flagstaff B/W	1125-1200
				1	Verde B/Grey	1150-1400
				1	Tuzigoot W/Red	1300-1425
				1	Gila Polychrome	1300-1400
	Room 2, Sec. B Fill	2	1134			
		1	1458	1	Tusayan B/W	1225-1300
	Room 2, Unit II, Fill (underlying Sec. B)	1	901	3	Tusayan B/W	1225-1300
Ariz. N:16:31	Room 1, Sec. 1, Fill	1	817			
		1	982			
		1	1134			
		3	1205	1	Tusayan B/W	1225-1300
		3	1273	1	Awatovi B/Yellow	1300-1400
		6	1338	1	Jeddito Plain	1300-1625
		7	1458	3	Jeddito B/Yellow	1325-1600
		2	1513			
		4	1566			
		3	1615			
Ariz. N:16:46	Room 1, Unit I, Fill	1	1338	1	Gila Polychrome	1300-1400
		1	1615	1	Tonto Polychrome	1300-1400
				1	Jeddito Plain	1300-1625
Ariz. N:16:80	Surface Survey	1	1273	1	Jeddito B/Orange	1200-1300
		1	1338	2	Awatovi B/Yellow	1300-1400
		1	1556	3	Gila Polychrome	1300-1400
					Jeddito B/Yellow	1325-1600
Ariz. T:4:54	Surface Survey	1	640	1	Sacaton R/Buff	1000-1200

A number of samples of obsidian were submitted to UCLA for obsidian hydration analysis (Table 4-I). These samples provided us with our only absolute dates for sites in the test area. It should be noted, however, that the distribution of these samples, as with the ceramics, was generally restricted to the Upper Sonoran Mesa-Canyon complex.

4.1.2. Environmental Conditions

The reconstruction of paleoenvironment is at best a highly inferential proposition and at worst, impossible to accomplish. For example, an assessment of prehistoric rainfall distribution and its concomitant effects on human activities could not be accomplished. Rainfall records for this part of the state have only been kept in recent years and then only sporadically. The nearest major weather station is in Phoenix, but the records here are also relatively recent (about 100 years) and would have little applicability to the northern half of our study area. In such a situation the investigator is faced with two basic alternatives. Either he disregards the variable of rainfall distribution entirely or makes the unverifiable assumption that the modern records are indicative of the prehistoric conditions. In evaluating the archaeological evidence the project team has opted for the second alternative.

The archaeologist must call on the specialists for analyses of different kinds of data which in an ideal situation would contribute to a knowledge of past environmental conditions. Traditionally, these fall into four categories:

1) Analysis of fossil pollens and macroscopic plant remains collected in samples from archaeological sites and water management/land use systems.
2) Analysis of faunal, and specifically, avian species from prehistoric contexts.
3) Analysis of tree ring samples by dendroclimatologists.
4) Analysis of surficial geology, particularly with regards to alluvial and colluvial depositional cycles.

Each of the above techniques was attempted in the study area.

Numerous soil samples for pollen were collected from each excavated site and from water management/land use systems. In the event that prehistoric pollen is preserved in significant quantities (generally 200 grains/sample) analysis should at the very least indicate which plant species were present and in what amounts, vis-a-vis one another. Much the same idea is applied to the analysis of macroscopic plant remains, collected by means of flotation techniques.

Both pollen and flotation samples were submitted to Dr.

Vorsila Bohrer of Eastern New Mexico University for analysis. Currently, we have received only preliminary results from her. These indicate the presence of maize from some site and systems sampled. Bohrer (personal communication) has further noted that the material in flotation samples from the Upper Sonoran Mesa-Canyon complex "may indicate" greater effective moisture during the period AD 1250-1450. Beyond this we have no current information as analyses are still being undertaken and will not be completed prior to the submission of this report.

Identification of faunal species, and most especially the avian species has also been completed in only a preliminary fashion. The identification of the remains of whistling swan from Ariz. N:16:31 in the Upper Sonoran zone lends some support to Bohrer's suggestion of greater effective moisture. According to Dr. Lyndon Hargrave (personal communication) the whistling swan is no longer found in this area, as it requires a standing water habitat. Unless this species was imported by humans from elsewhere (the remains of only one individual has so far been identified) a situation different from today's regimen would have necessarily prevailed. The specific nature and extent of the standing water habitat in prehistoric times remains unknown at present. Its indicated presence does lend impetus to the suggestion that more water was available in

the past. If there are other key indicator species in the faunal assemblages they have not yet been identified.

We had hoped to collect tree ring samples for dendroclimatological analysis as another means of understanding past environmental conditions. We were prevented from doing so by poor preservation of organic materials and lack of sufficient trees. In the Upper Sonoran Mesa-Canyon complex there are some stands of juniper (Juniperius sp.) thought to be no older than 300 years. In the transition zone tree wood does not appear to have played a major part in construction. No samples amenable to analysis were recovered.

Thor N. V. Karlstrom (USGS) has analyzed the alluviation-colluviation cycles that characterized areas adjacent to the study area in the past. From studies of alluvial deposits along the Gila River and through cross-correlation with other areas in Arizona and the Southwest three major alluvial cycles since AD 1 have been delineated. (Karlstrom, personal communication). The X deposition began ca. AD 350 reached a maximum ca. AD 600. The Y deposition began ca. AD 875-900 and reached a maximum ca. AD 1150. The deposition began at ca. 1450 and reached a maximum ca. AD 1700.

The findings would indicate generally wetter conditions than present from AD 900+- to AD 1150+- when the maximum of the Y depositional activities occurred. From then to AD 1450+-

conditions tended toward dryer conditions. Our interests center on the period of AD 1000-AD 1450. Correlations between geological and dendroclimatological studies in regions in the Four Corners area suggest a period of less than normal (mean) precipitation between ca. AD 1150-1300. Generally speaking this trend persisted until ca. AD 1450.

It must be pointed out that simple precipitation statistics can be deceptive with regard to prehistoric populations. There are many other variables which cannot yet be adequately measured or described, seasonality being primary among them. It matters little if an area receives 15 inches of precipitation per year if it all comes at the wrong season to be useful. Within our specific study area we simply do not know as yet what the consequences of lower than average annual rainfall were. Our archaeological evidence suggests that for 200-400 years the test area was inhabited and intensively exploited by semi-sedentary to sedentary human populations. Abandonment between AD 1400-1450 may well have been a consequence of a dryer weather cycle.

4.2 ADAPTATION

The object of the discipline integration is to evaluate the adaptation made by pre-Columbian man to the semi-arid Southwest. As noted previously, the inter-disciplinary

approach to the project provided the answer to some of the basic questions concerning the environment of the test area. However, the principal input for the adaptation section was provided by the archaeologists. Questions of culture history, the nature of cultural boundary systems and the cultural interrelationships of groups within the test area were approached by the archaeologists. Several models are presented which offer hypothetical solutions to the data retrieved. It was generally felt by the archaeologists, from the onset of the project, that the understanding of the human adaptation to the test area would necessitate the employment of models geared to shifting patterns of land and water utilization. By constructing such models, a detailed examination of land use and water management systems is possible.

4.2.1. Exploitation Models

Our interests in the hydrology of prehistoric farming systems led us to attempt to associate specific man-made systems with specific archaeological sites. We realized early in the field studies that this was an impossible task to accomplish because of the lack of diagnostic artifacts which would have linked sites and systems. Therefore this aspect of our work still remains a problem to be solved. We have chosen to use proximity as our measure for interpreting the evidence.

Although an understanding of culture history in the study area is an important element to consider in assessing the nature of prehistoric subsistence and adaptive strategies, current data allows only for speculation. We have instead concentrated on deriving models of exploitation, one or a combination of which might aid in our understanding.

Prior to our field studies our knowledge of the nature and extent of exploitation in the study area was limited. We knew of a series of habitation sites in the Lower Sonoran Basin and Range region. There were records of hilltop masonry sites in the transition zone which were "defensive" or at the very least "defendible" sites (Gumerman and Johnson 1971). Next to no archaeological information was available for the area encompassing the Upper Sonoran Mesa-Canyon complex.

Our field investigations have established that the most intensive exploitation of the study area prehistorically had occurred in a 200-400 year span (ca. AD 1000-1400). This information, however, did not allow us to precisely define the <u>nature</u> of the exploitation. It was clear that sedentary or semi-sedentary horticulturalists had utilized the area's resources but diagnostic artifactual data which would have allowed for an in-depth assessment of the social and natural boundary systems were lacking. Hence the development of the models of exploitation seen schematically in Figures 4-1a,b, c,d,e,f and described below. We do not claim to account for

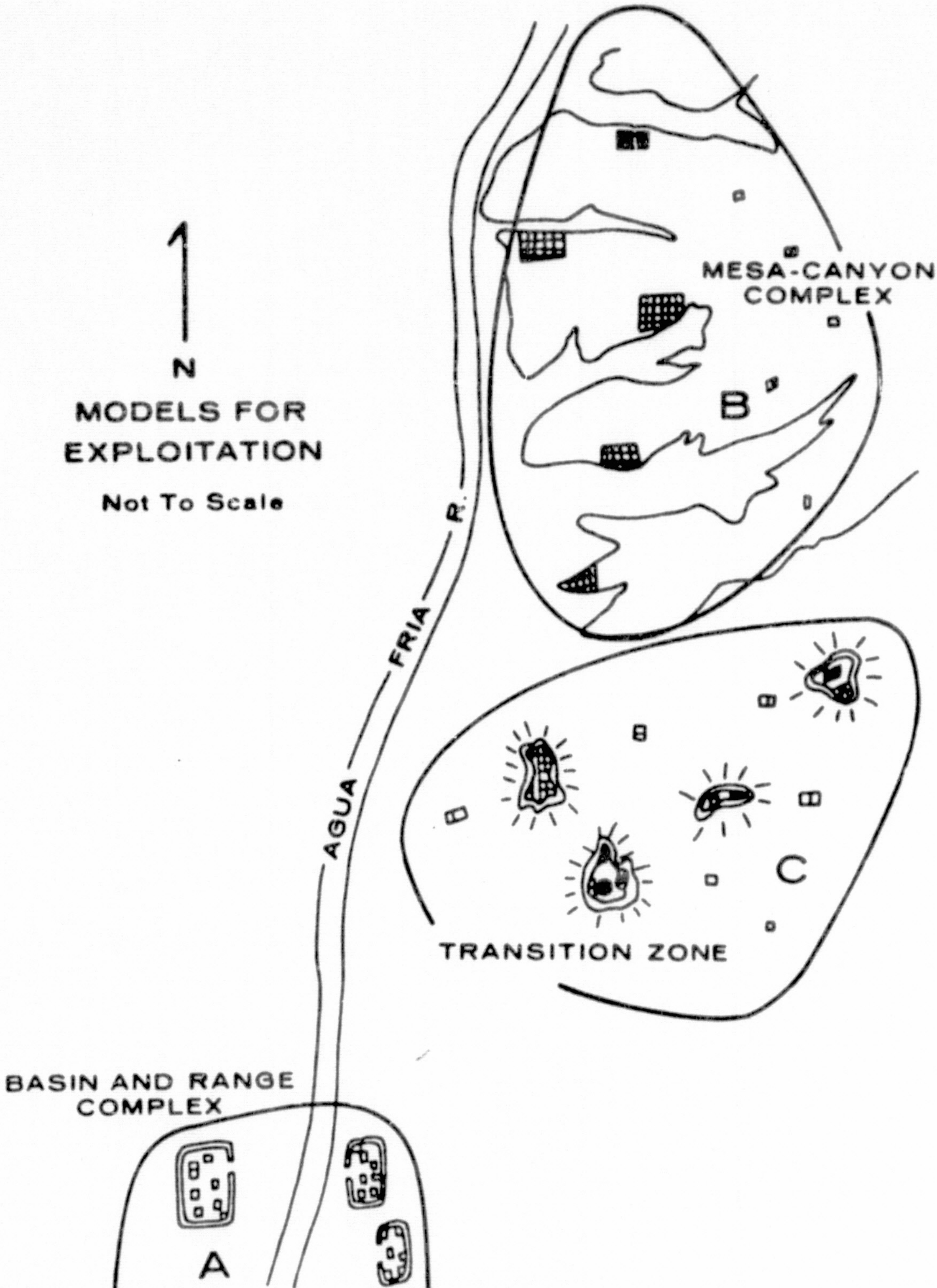


Figure 4-1. MODEL 1 FOR EXPLOITATION OF STUDY AREA.

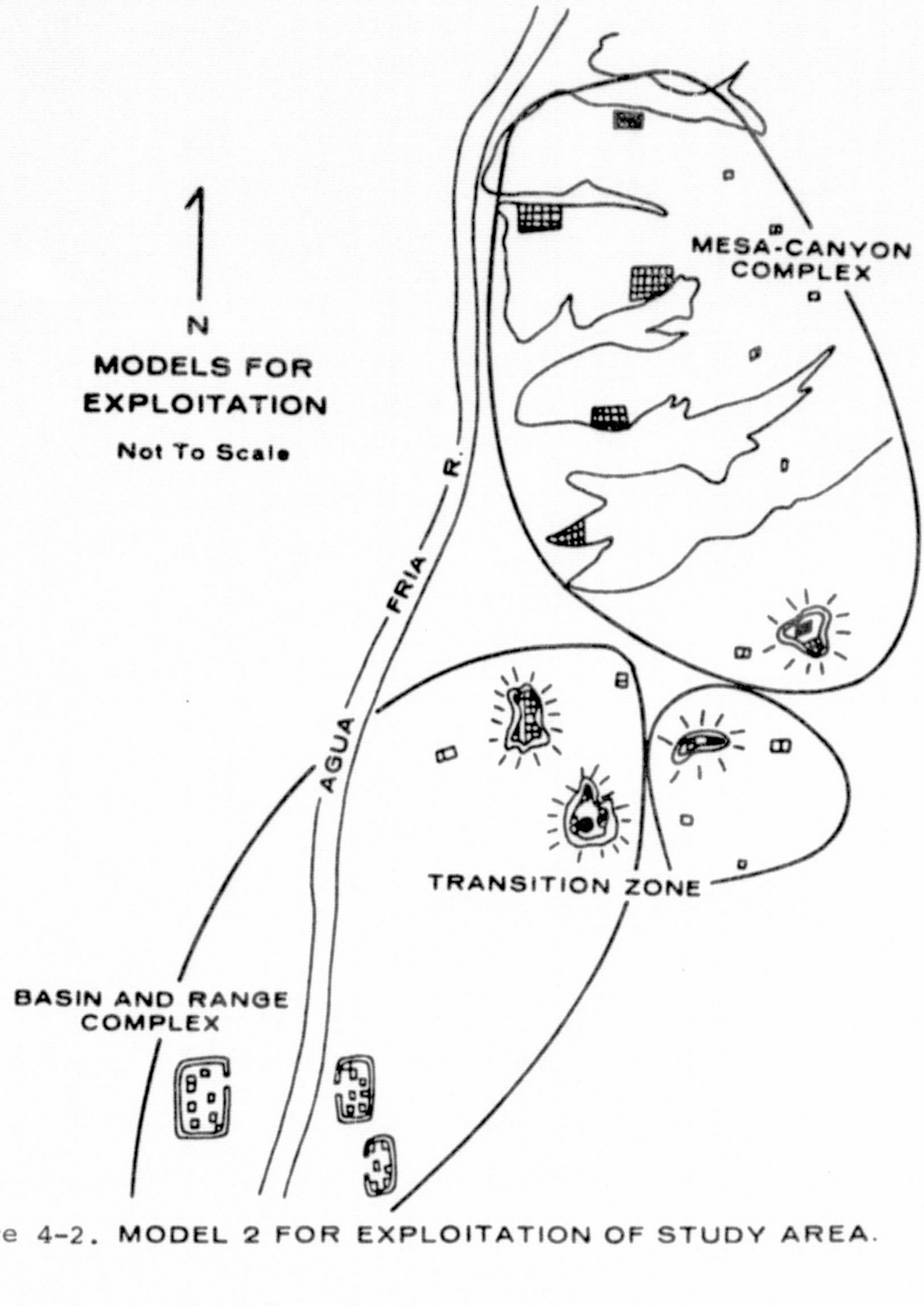


Figure 4-2. MODEL 2 FOR EXPLOITATION OF STUDY AREA.

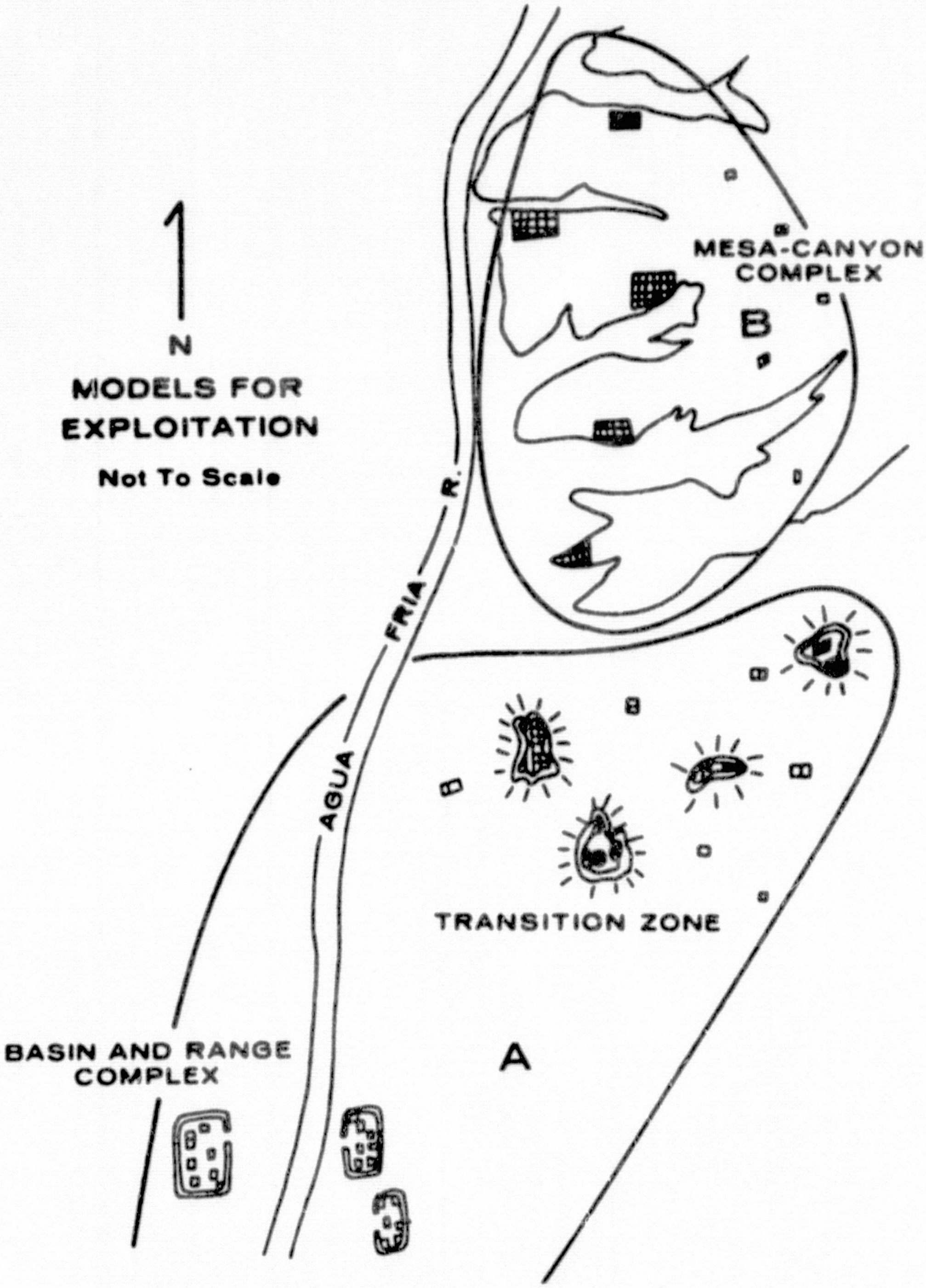


Figure 4-3. MODEL 3 FOR EXPLOITATION OF STUDY AREA.

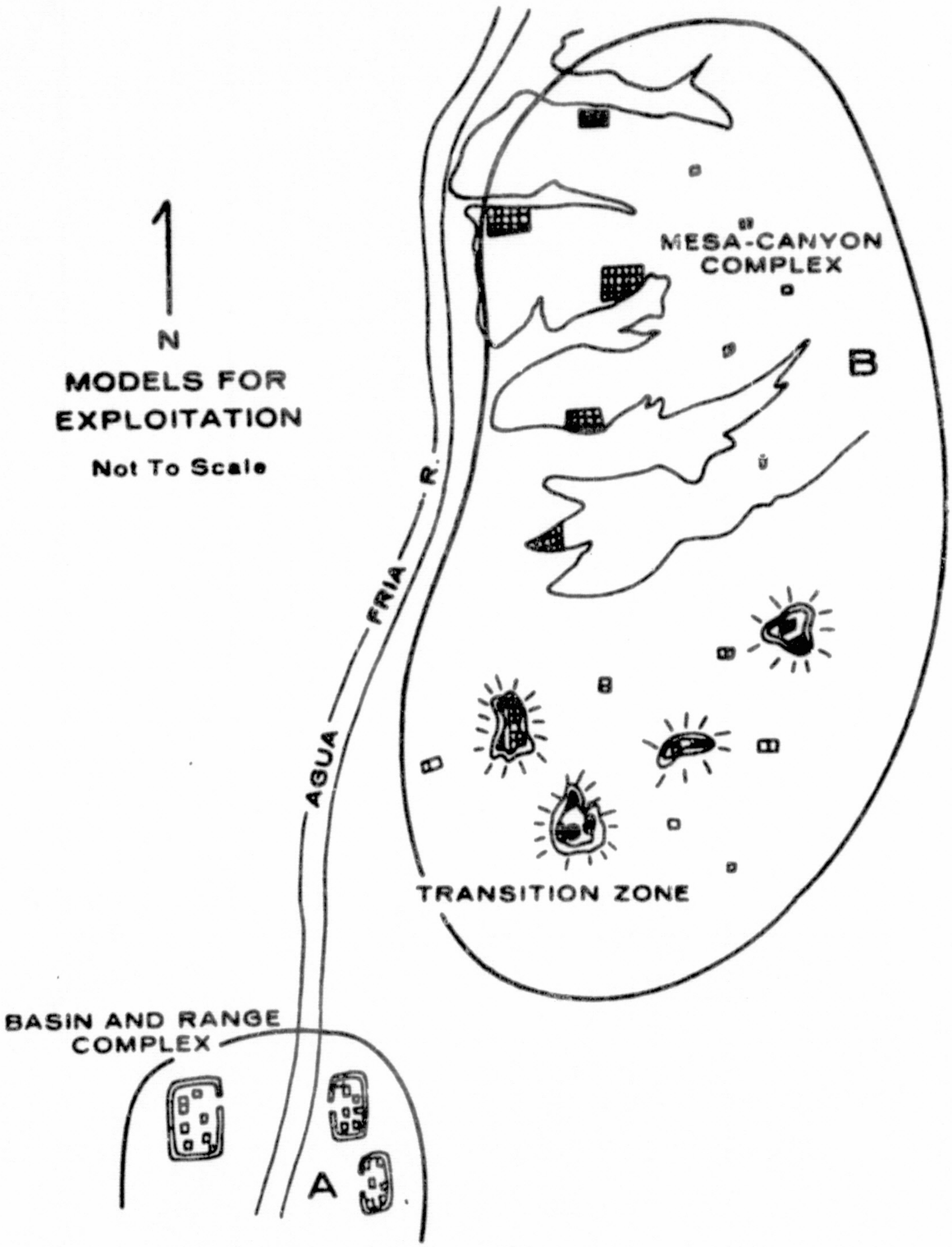


Figure 4-4. MODEL 4 FOR EXPLOITATION OF STUDY AREA.

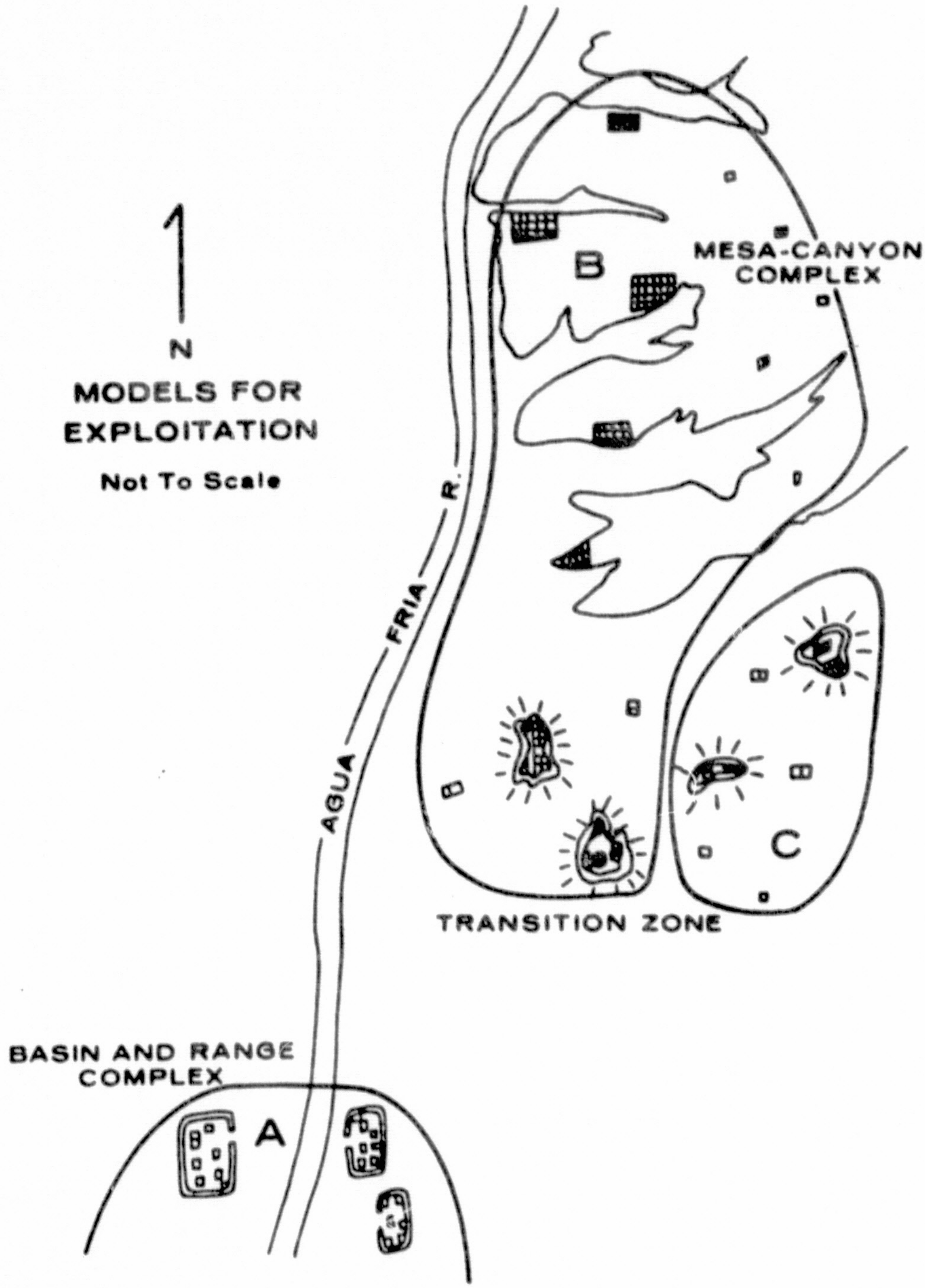


Figure 4-5. MODEL 5 FOR EXPLOITATION OF STUDY AREA.

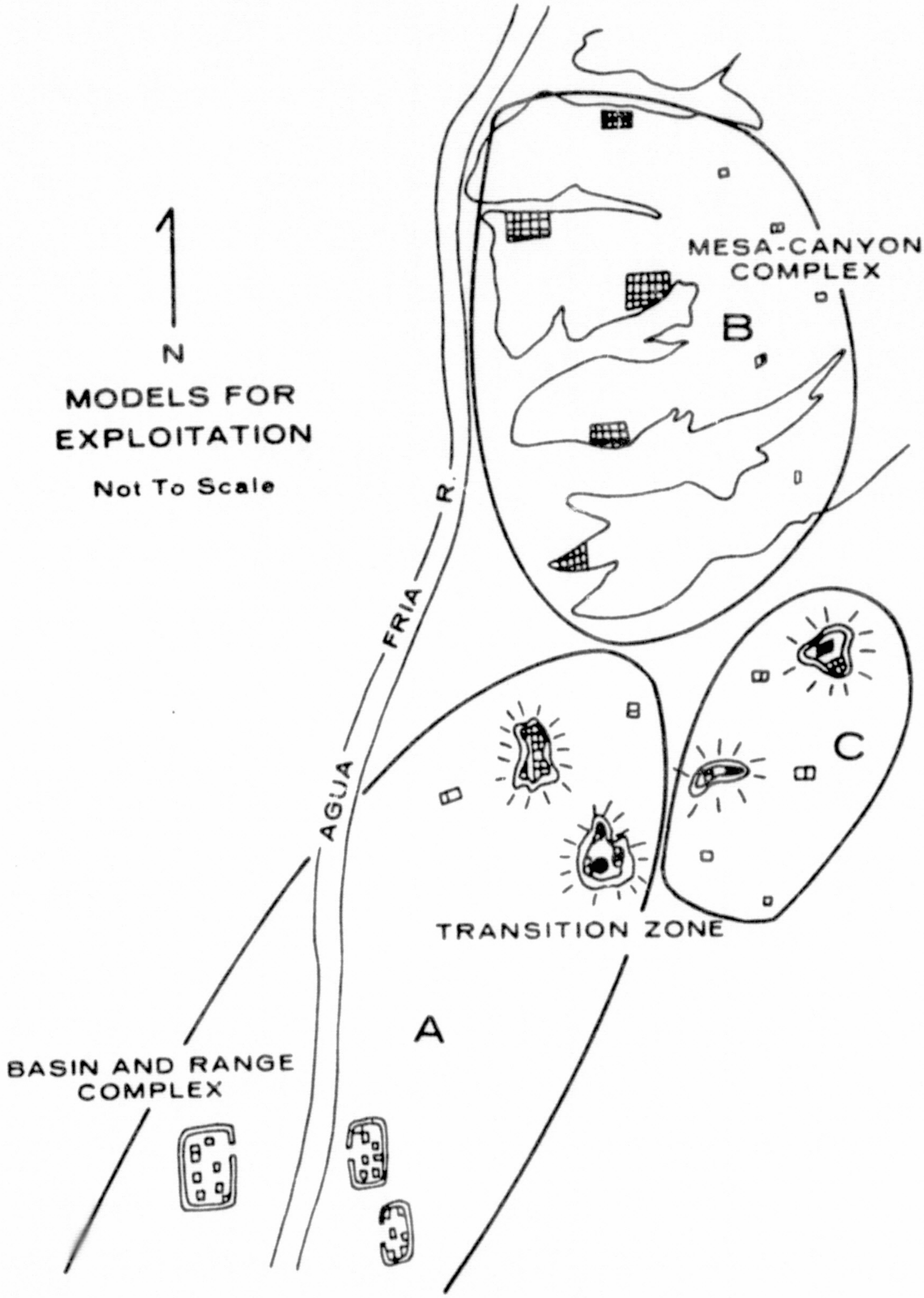


Figure 4-6. MODEL 6 FOR EXPLOITATION OF STUDY AREA.

all possible variability with these six hypothetical statements. For example they do not account for the activities of nomadic peoples who may have exploited selected wild floral and faunal species at specified times of the year. They are further constrained by the assumption of general contemporaneity between and among sites and areas, which we have had occasion to note cannot be confirmed.

Model #1 -- This model postulates three distinct socio-cultural groups exploiting the major sub-areas of the study area. Each of the groups is presented as a separate entity more or less exploiting the resources specific to its home area. Interaction between groups would have been almost invariable but we do not speculate as to whether the interaction was friendly or hostile. The presence of hilltop sites in the transition zone indicate that at least the threat of hostilities was present.

Model #2 -- Three distinct groups exploit the area but the range of that exploitation has changed for each from model #1. As with the others, this model focusses on the transition zone. This area is pivotal either for the land itself and/or the resources to be found there. In this model the populations whose base is generally outside the transition zone utilize the transition zone as much or more so than the group living only in the zone. In this model the major cultural boundary

situations are to be found in this central area.

<u>Model #3</u> -- Only two major social groups inhabit the area. The group based in the Lower Sonoran Basin and Range region has extended its territorial base into the transition zone. The people inhabiting the Mesa-Canyon complex are restricted in their subsistence activities only to that zone.

This model appears particularly applicable given the apparent downturn in the fortunes of the people of the Salt-Gila Valley during this period (cf. Bohrer 1970). The transition zone offered resources no longer easily attainable in the Lower Sonoran zone as well as some Upper Sonoran and unique species. In fact, this model does not draw great support from currently available data.

Model #4 -- This is a mirror image of the preceeding situation. In this instance people whose home base was in the Upper Sonoran Mesa-Canyon complex who extend their territory into the transition zone. This model was derived from the fact that while the largest habitation sites so far identified occur in the Upper Sonoran zone, the potential areas for farming in that zone are restricted. More acreage and greater variety was available in the transition zone. Additional support for this explanation came from discussions with other investigators in adjacent areas who had also noted an apparently similar pattern of mesa-top habitation and lowland agricultural

exploitation (A. E. Dittert, personal communication).

Model #5 -- Although three cultural groups are hypothesized the relationships between them are changed from preceding discussions. In the pivotal transition zone this variant hypothesizes exploitation by only 2 of the 3 groups, in this case the Upper Sonoran and transition zone peoples. People of the Lower Sonoran are excluded.

Model #6 -- A mirror image of model #5. In this case the Upper Sonoran peoples are restricted to that zone for purposes of conducting subsistence activities. Exploitation of the transition zone is shared by the indigenous population and people from the Lower Sonoran zone.

4.2.2 Water Management Strategies

As we cannot yet clearly determine the nature of culture boundaries in our archaeological data, we have chosen to focus on the strategies adopted by prehistoric societies for management of water and use of land. The nature of water management/land use systems found in the test area has been discussed elsewhere in this report. We have defined the following types of hydroagricultural schemes: terraces, linear alignments, linear borders, check dams, canals and waffle gardens. We have noted the probable existence of cleared plots and flood water terraces and fields.

In many cases the different types of systems appeared to have functioned in combination with one another. The most extensive systems are located in the transition zone. The hydroagricultural complexes represent functional, minimal energy expenditure systems ideally suited to the topographic and hydrological potential of the area. Topographic variables are key indicators of which individual or combination of management systems are found in which localities.

Minimum energy expenditure systems are land use strategies which did not require large organized labor pools for their construction and maintenance. All systems identified to date in the test area, with the possible exception of the waffle gardens and long canals, could have been constructed by one household, a loosely interdependent extended familial group, or other volunteer groupings of people. It would appear from available evidence that what was essentially a mini-max strategy was in operation. In this strategy minimum time and energy expenditures (costs) are hypothetically geared to maximum returns (benefits) in terms of crops yielded and area utilized.

It is true that many systems in the study area are substantial in extent. Extensive systems are particularly characteristic of the transition zone, but it is also clear that these systems and the natural factors involved would not

lend themselves to intensive cultivation. The majority of water management systems are rainfall dependent and represent strategies which allow for the maximum deployment of available runoff over the largest possible area.

Runoff is only one of a number of variables that must be understood in analyzing decisions of prehistoric populations having to do with water management. As we had no way of reconstructing the actual decision-making process, it was necessary for us to utilize a model based on relative costs and benefits of particular strategies in particular habitats (Plog and Garrett 1970). The model is also explained by Plog in the Archaeology of Arizona (Martin and Plog 1973).

In assessing the diversity of water management and land use systems in the prehistoric Southwest it is clear that one cannot speak of kinds and types of systems which are restricted exclusively to any particular socio-cultural group. There is a great deal of variability reported from region-to-region and valley-to-valley. It therefore appears that the proper unit of analysis is the region. In the central Arizona region we are most interested in variability within and between the three major sub-areas of our overall study area.

Costs -- The cost of one type of agricultural practice over another varies with a given situation. 1) Preparation costs: There are minimal preparation costs involved when a

population simply sows seeds into unprepared ground. A higher preparation cost is incurred by the population which significantly alters the landscape.

2) Maintenance costs: Groups sowing seeds and then leaving fields unattended incurred no maintenance costs. If fields needed maintenance, costs rise. If cleaning canals and repairing terraces are involved, maintenance costs rise even more.

3) Opportunity costs: This notion is based on scheduling decisions given various constraints. For example, a group which plants a crop but then leaves the area to pursue other activities incurs few opportunity costs. Time is still relatively free to pursue these other activities. Irrigation on the other hand, may necessitate that the population remain at or near the fields throughout the growing season, substantially reducing opportunities to carry out other subsistence activities.

4) Costs incurred due to the negative effects of some land use systems on the environment. It would appear likely that prehistoric populations in the Southwest increase soil alkalinity, perhaps by over-irrigation, thus forcing abandonment of fields for considerable periods of time, perhaps even permanently.

<u>Benefits</u> -- Different agricultural practices are associated with different benefits.

1) Benefits that result in increases in the production of a crop per unit of labor input.

2) Benefits which act to increase the gross product without necessarily increasing productivity.

3) Benefits that increase group security by, for example, making a potential resource available at a time in the annual subsistence cycle when resources were scarce.

No precise relationship need exist among these various kinds of benefits. Problems of evaluation of benefits are complex. Moreover, cost and benefits associated with given techniques varied with the habitat in which the system was placed.

Two data sets are crucial to the Plog and Garrett model (see Figure 4-7).

1) Information on the habitat in which the system is being constructed, and

2) Information on the tolerance of system components for relevant habitat variables.

According to Plog and Garrett, the most important habitat variables in the determination of which system will provide optimum benefit in a given locality are slope, soil, type of surface water available, yearly rainfall distribution, and dedadic rainfall distribution. To this should be added amount

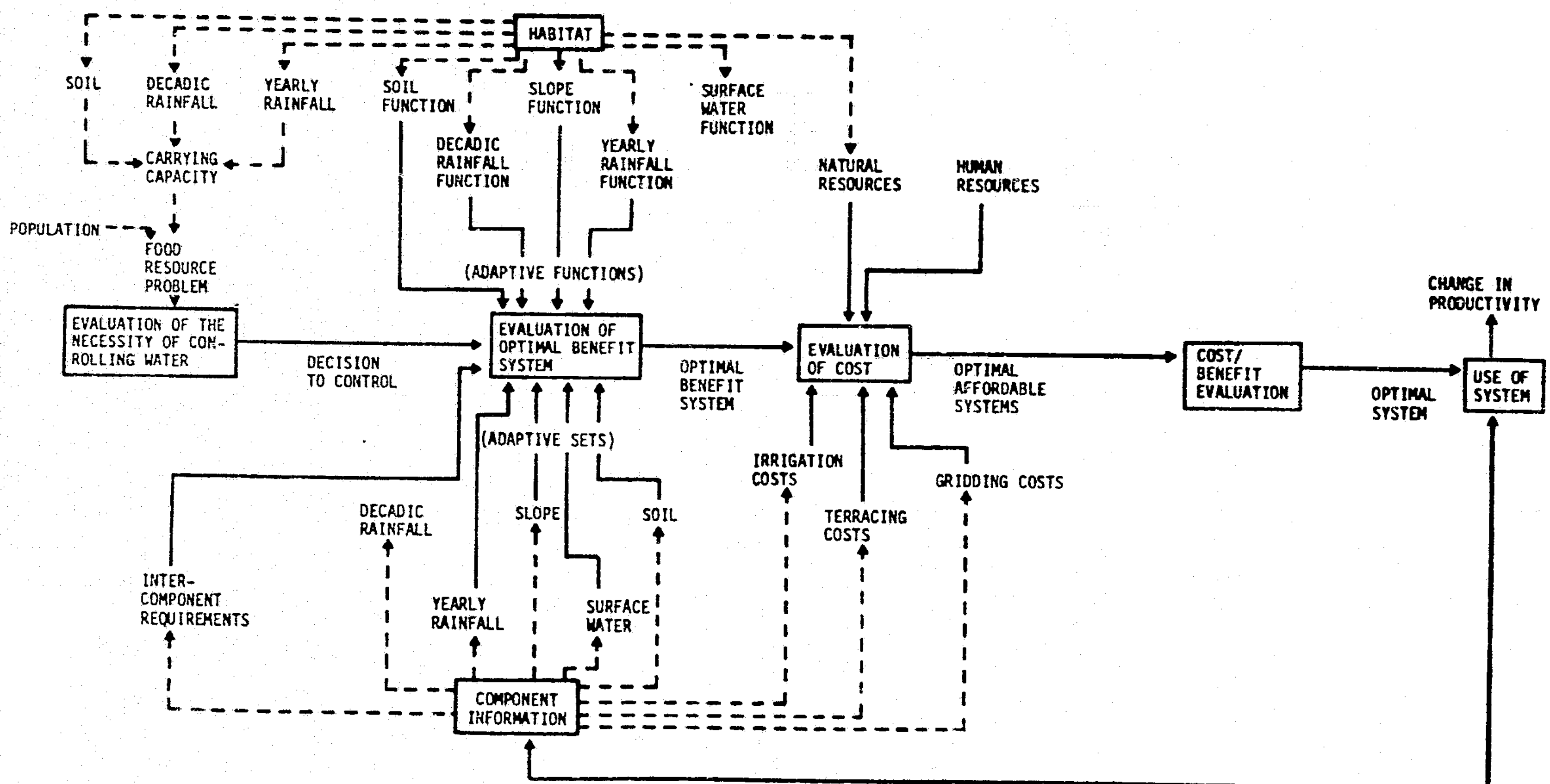


Figure 4-7. A MODEL OF THE RELATIONSHIP BETWEEN HABITAT AND WATER CONTROL STRATEGIES. (AFTER PLOG AND GARRETT 1970)

TABLE 4-II

COMPARISON OF WATER MANAGEMENT SYSTEM WITH SLOPE

(After Martin and Plog 1973)

Component	Most Efficient	Tolerance Range
Irrigation	1%	.1-10%
Terracing	12%	5-35%
Gridding	5%	1-20%

of surface water available. For each variable a value can be obtained for which each system component will provide optimum benefit and a range between which values some benefits would be derived. One could, for example, compare the relationship between gridding, terracing and irrigation and the variable slope.

If a case arose in which alternative systems could be used in a single locale, the costs of the system would be the principal determining factor in the decision of which to employ. Today, terracing is approximately twice as costly as gridding, and irritation is approximately twice as costly as terracing. It is felt that the relative costs were probably similar prehistorically (Martin and Plog 1973:294).

4.2.3 Sub-Area Evaluation

The Plog and Garrett model cannot yet be formally applied in the CAEP test area, as we cannot provide data on such variables as yearly rainfall distribution. Despite this liability, the model is important as a heuristic device through which our particular data may be relatively ordered. The model also serves to identify those parameters in the natural environment that could have required changes in the adaptive mode. As mentioned these include slope, soil, and type and amount of surface water available. It should be noted that in a region

similar to our test area, vegetation would not be a major variable to contend with when deciding about locations and types of systems.

The general cost/benefit model seems particularly applicable in the study area. There are numerous kinds of water management and land use systems which have been identified in our investigations. It will be noted that particular types of systems are not restricted to specific sub-areas except for the waffle gardens and long canals identified only in the Lower Sonoran Basin and Range Province.

In the Upper Sonoran Mesa-Canyon Complex terraces, linear borders (gridding), cleared land, flood plain, and other systems have been recorded. In the transition zone highlands we have identified terraces, cleared plots (another form of gridding) and a system whose type is unknown.

In the transition zone lowlands there are linear borders, check dams, terraces and flood plain agriculture, as well as systems listed as miscellaneous. In the Lower Sonoran Basin and Range Province there are waffle gardens and canals.

This distribution, particularly in the northern 2/3 of the study area, suggests that the natural environmental variables, particularly in the realm of topography and water accessibility, are as important, if not more so, than cultural variables in making decisions regarding water management and land use.

It should be noted that the water management and land utilization systems were not geared towards irrigation, with the obvious exception of the long canal in the Lower Sonoran. Rather they were aimed at dry or flood water farming using water available through precipitation and runoff. Clearly, these kinds of systems would not be sufficient for any cash crops today, but were very effective on a subsistence basis. The study area is well within the tolerance of water needs for dry farming today, but the possibilities for double-cropping, thought to have been an important subsistence strategy in the Salt-Gila Valley to the South, may have been more difficult in the higher elevations of the study area. In many instances also, we have recorded systems that combine more than one general type. This was most frequently seen as a combination of terraces and linear borders, although occasionally other combinations were also defined.

The Mesa-Canyon complex is characterized by these two major physiographic features. The mesas are relatively flat, with some relief in the western portion. The canyons tend to be steep-walled and deep. There are many areas of bedrock exposures throughout the sub-areas. On the mesa-top, there are numerous boulder fields. Soil cover in this area is shallow and runoff rates are difficult to gauge. The columnar basalt bedrock acts in concert with the thin soil cover to increase

the rate of ground water infiltration. There are relatively few areas suitable for flood-water farming, except at the mouths of tributaries to the Agua Fria River.

Through use of the Plog-Garret model, archaeologists predicted that system extent would be restricted and would consist of utilization of all favorable areas. It was further predicted that relative system costs would be greater in this area than others due to probably decreased benefits. Therefore, it was predicted that systems in this sub-area would be those which could be constructed and maintained in the least costly way. We predicted that the more costly systems (terracing and irrigation) would have been utilized minimally. These predictions assume that the decision to control water in the first place is primarily due to a food resource problem.

Our predictions were generally accurate. The extent of the systems in the Mesa-Canyon complex are less than that noted for the transition zone. Although our figures are somewhat speculative, it would appear that less than 1/2 of the acreage under cultivation in the transition zone was under cultivation in the Mesa Canyon complex. Essentially then, we are speaking of fewer systems over a smaller amount of land. Cleared land (including land listed as potentially useful) was a major system type. Usually found on the flat areas between canyons, it was an efficient system for this area, as it could

be constructed simply by removing the larger rocks from fields. Cleared land systems were invariably located on slopes averaging 4% or less. This was necessary given the runoff characteristics on the mesa-top, and that no diversion systems were found in association with the cleared land systems. Conceivably more cleared areas may have been used as fields but they went unidentified. Identification of this type of system is impossible from the imagery and often even on the ground.

Linear borders, another relatively low-cost system, were also restricted in extent. The nature of the mesa-top argued against wide use of this type of system. They were most difficult to build in the mesa boulder fields. Of the five examples identified, all but one fall well within the slope tolerance range suggested by Plog and Garret (Table 4-II). Notably, however, these systems tend to be quite small when compared to the same type in the transition zone.

The prehistoric populace on the mesa made excellent use of opportunities afforded for flood plain farming. Ten different systems were noted in the area. Half of these were located at the mouths of Baby and Lousy Canyons. The other half were located on slopes or mesa flat land. While the latter were not in alluvial areas as would normally be expected, they took advantage of favorable slope conditions and were located in areas which would have enabled the capture of the greatest

amount of runoff. In some cases the fields received amounts of water many times greater than would be possible through direct rainfall. Flood-farming may have been very important throughout the test area. Although within the limits of land which can be cultivated by dry farming, this area is approaching the lower limits. Fields which were cultivated only through precipitation would be poor safeguards during years with less than normal precipitation. One means of insuring against drought and perhaps a way of raising yield as well is to choose locations for some fields in which they will receive runoff from acres located above them. Not all fields can be so situated, however, as during years of greater than average precipitation many flood fields would receive too much water, drowning or washing out crops (Hall 1974).

Our predictions concerning the use of systems in the Mesa-Canyon complex were least accurate regarding the use of terracing. Terracing is an expensive system to utilize because of high construction, maintenance and opportunity costs. Further, our image interpretation had led us to conclude that there were very few areas suitable for terracing in the Mesa-Canyon complex. Only the sides and rim areas of Baby Canyon and the mouth of Larry Canyon seemed appropriate. In fact, it appears that all areas suitable for terracing in the area we covered on foot were utilized. Upon closer examination,

however, we found that the prehistoric peoples were cutting the costs of terracing to a minimum by utilzing and sometimes moderately refining natural terraces. The systems of terraces (and borders) provided good locations for fields that did not necessitate a great deal of time or effort to prepare. This situation allowed the people to use time and energy for other subsistence pursuits. The use of naturally occurring terraces also helps explain the anomaly of a relatively expensive system situated in areas where the slope variable is at the extreme tolerance limits. In two cases the tolerance limit was exceeded by a factor of 5%. In another case the terraces were located on a slope of 5%, at the lower limits of the tolerance range. In two cases the slope was within the tolerance limits but was not close to the optimum slope for this category (maximal efficiency from 12% slope).

The transition zone presented both different opportunities and problems to the prehistoric occupants. As a zone, perhaps the biggest difference is in the accessibility of variable vegetation communities. The nature of the transition zone is such that more species were available for exploitation. This created greater opportunities for alternative modes of subsistence activities. Although heavily dissected, there are sizable flat and gently sloping areas which would have served as suitable places for site and system location.

The zone can be roughly divided in terms of elevation. The highlands are very reminiscent of the Mesa-Canyon complex, with vegetation comprised of greater amounts of grasses and yucca and less prickly pear than the lowlands. Bedrock types in the transitional zone highlands are the same noted for the Mesa-Canyon complex, i.e., faulted volcanic rocks, tuffs, and especially basaltic flows with some interbedded alluvium.

The lowlands of the transition zone have vegetation communities reminiscent of the Lower Sonoran Basin and Range country. Although bedrock types tend to vary by specific location, the areas in which our ground truth activities were carried out is characterized by older terraces and alluvial fans. Away from the highlands escarpments such as New River Mesa, the transition zone becomes much more gentle with regard to slope.

The differences between the uplands and lowlands, would, according to the Plog-Garrett model, lead the archaeologist to predict some differences in water management and land use between the two. Accordingly, after viewing the imagery, the archaeologists predicted that the highlands areas would have been exploited in ways similar to the Mesa-Canyon complex. This would mean water management/land use systems of restricted areal extent, many cleared areas, some use of linear borders and the use of more expensive kinds of systems such as ter-

racing only when the natural formations permitted use as a terrace without necessitating high construction and maintenance costs.

Archaeologists predicted a somewhat different distribution of system types in the lowlands, where slope and soil cover were less prohibitive factors. In lines with the cost/benefit model, we felt that systems in the lowlands would be generally greater in areal extent than those noted in the highlands. In rating the amount of runoff that could conceivably be generated in the lowland area, we felt that systems with higher built-in costs would have been more likely to have been constructed here than elsewhere. Noting the potential runoff from highlands escarpments and the low mountains that were encountered, we anticipated locating check dams to slow this runoff, and diversion systems such as linear alignments to get the slowed water to the appropriate fields. The numerous small washes and major streams in the area combined with a gentle slope in the flat-lands led us to predict the existence of substantial floodplain fields. We predicted use of terracing particularly in the steeper areas near the southern and western escarpment of New River Mesa. Finally we felt that in some particularly flat areas major washes could have hypothetically been watered by irrigation and the occurrence of canals was expected.

Our predictions for the highlands areas did not have a high degree of accuracy. Whereas the flat mesa tops in the Mesa-Canyon complex appeared to have much land not being utilized for purposes of cultivation, New River Mesa was covered with systems. The reason appears to have been a combination of factors, most notably slope and soils cover. The same phenomenon of basalt boulder fields that had been encountered in the Mesa-Canyon complex were also noted here, but with one major difference. On New River Mesa these fields tended to be higher than the area surrounding them. Soil cover in these fields was practically non-existent, but the cover around the boulder fields was deeper than that noted in the Mesa-Canyon complex. This soil deposition made water management and land use systems more feasible. Further, conditions suggested that extensive systems of linear alignments (linear borders), involving lower costs than terracing or canals, would have been a useful subsistence strategy.

During the ground truth activities in the transition zone highlands we noted that very extensive systems of linear borders were below these boulder fields. In some cases the systems completely encircled the fields and in other cases they were restricted to two or three sides. In noting the location of these systems it appeared that water was being channeled from the higher boulder fields into the linear border systems. In

some cases this may have been aided by the use of check dams, which acted to slow the runoff rate. The linear borders would have functioned as diversion mechanisms.

Near the heads and down the sides of canyons which dissect New River Mesa in a north-south direction many terraces were recorded. Generally the inhabitants had, as expected, made use of natural terraces in these areas, but in many cases had constructed terraces between them. The relatively steep and deep walled canyons would have permitted a great deal of runoff. This combination of terraces interspersed with linear borders provided an ideal means by which to slow, divert and utilize such water, even given the relatively high cost associated with system construction and maintenance.

Our prediction for systems of greater areal extent than noted in the Mesa-Canyon complex proved correct. As expected, a popular form of land use system in the transition zone lowlands was flood plain fields. These occurred near major sites and with only two exceptions were located within 100 meters of the nearest stream. In all but one case these were located on relatively flat terrain (4% slope or less). The one exception, however, was on a slope of approximately 10% and was the most extensive system of this type in the lowlands.

We recorded many more terraces in the lowlands than had been expected, to the point where they appeared to be the most

utilized strategy. Although the presence of numerous terrace systems was not unexpected, the location of many of the terraces was. We had predicted extensive use of terracing on the slopes making up the southern and western portions of the New River Mesa escarpment. This was an area which combined numerous natural terraces necessitating little if any modification with a slope percentage well within the tolerance limits.

Fifteen terrace systems were recorded in the lowlands. Their presence is an anomaly because in 12 cases the slope is below the minimal beneficial tolerance level for this type of system (5%). An additional system is at 5% slope. The other two examples are on slopes of 10% (nearing the best grade for terraces), and 12%.

This apparent anomaly cannot be satisfactorily explained at present. As the construction and maintenance of terrace systems is more costly than gridding (linear borders and alignments) and demands greater relief for optimal benefits, it would not be predicted, on the basis of Plog-Garret model, that they would have been constructed in areas which superficially suggest the use of the less costly type. One possible answer to this dilemma is that though these systems were recorded as "terraces" they were built as linear alignments which had been constructed perpendicular to the slope. There is no way to ascertain the validity of this hypothesis without extensive

rechecking on the fields. In many cases the two kinds of systems do look somewhat alike, and a simple mistake in identification would not be surprising. All we can say at present is that these "terraces" do not conform to the predictions generated by the Plog-Garrett model.

Numerous systems of linear borders were recorded in the lowlands, but not necessarily in predictable locations. It has already been noted that clearing land for use as fields would have probably involved far less energy than in the Mesa-Canyon complex. Building linear borders and alignments would have been hastened by the clearing process. In some cases the linear borders were combined with systems of terraces, similar to the systems noted in the heads of canyons in the transitional zone highlands. This combination of techniques is indicative of the basic knowledge these people possessed concerning the exploitability of various natural situations. A further example will clarify this point. Near the large hilltop site Ariz. T:4:8 there are extensive water management/land use systems in the form of linear borders on a varied slope. By postulating the system as a flat plane it was determined with the aid of a slope indicator that the percentage and angle of slope had been a determining factor of the angle at which the borders and alignments had been set. Furthermore, the location of the system allowed the prehistoric peoples to

utilize surface runoff from an area considerably larger than the system itself, perhaps 3 to 4 times larger. To the archaeologist this would seem to lend credence to the hypothesis that these prehistoric peoples were well aware of the natural environmental constraints imposed upon a subsistence strategy based to a greater or lesser degree on the cultivation of domesticated foodstuffs by dry farming. In a marginal area such as this, costs versus benefits needed to be weighed carefully. In the transition zone it would appear that this was accomplished in a practical but sophisticated manner.

The Lower Sonoran Basin and Range Province presented different problems for the prehistoric inhabitants from those that had to be dealt with in other postions of the study area. This zone includes large areas of relatively flat flood plains. Slope is extremely gentle. The desert floor is occasionally broken by low hills. The Agua Fria is the major drainage in the area, transversing the region in a primarily north-south direction. Vegetation is typically Lower Sonoran. Ground truth activities in this zone were, in the main, concentrated along both sides of the Agua Fria from the Lake Pleasant Dam South to Calderwood Butte. This included survey on the first and second terraces of the river.

The topographic nature of the portions of this zone

covered by our survey does not lend itself to the efficient use of some of the water management/land use systems that were identified in the Mesa-Canyon complex and transition zones. A prime example is the terrace constructions as slope in this zone seldom reaches the minimal tolerance limit of 5%. Also, linear borders and alignments which perform the double function of slowing down and diverting water in the other areas would be of little practical import under the circumstances noted in this zone.

In fact, of the kinds of systems discussed to this point, only three would be of particular use in this environment: flood plain fields, cleared land-garden plots and canals. This portion of the test area lies within the boundaries of the prehistoric Hohokam of the Salt-Gila Valley. These people were responsible for large systems of major irrigation canals, feeder ditches and fields throughout the area at the present site of Phoenix. As previously noted, water management and land use were most costly if the system employed consisted of irrigation canals. The construction costs are high, but maintenance and opportunity costs are even higher, sometimes to the point of requiring that people remain near the fields and canals throughout the growing season, thus greatly prohibiting the opportunity for other subsistence pursuits.

Archaeologists knew of at least one ancient canal near

the southern boundary of the test area (cf. Weed 1972). We predicted the presence of other such systems in the same general vicinity; south of the current dam where the flood plains open to great expanses to the east and west. Further north the areas bounding the Agua Fria seemed too constricted to warrant use of such a costly system. Ground truth activities located other canals. Only two major systems were identified in this portion of the test area; the canals and the ubiquitous waffle gardens.

The waffle gardens are located on terraces above the Agua Fria. These were an extensive system of garden plots which, viewed from the air, resemble waffles. Since pollen samples collected from these plots have not yet been analyzed we do not know what was grown in them. We are only able to speculate on the reasons for their construction. The majority were watered only by rainfall. Their location on isolated terraces seems to negate the possibility of watering by runoff diversion, except in a few cases. It is further difficult to assess the cost/benefit ratio with regard to this type of system. The elaborateness of construction and the areal extent of these systems would indicate high construction costs. Maintenance costs would have been very moderate, but opportunity costs may have been high as well, particularly in the event that such systems required watering by hand (a distinct

possibility) either as a normal course of events or during abnormally dry years. At present we simply have no way of knowing whether the Plog-Garrett model would be useful in predicting their existence.

We were surprised not to find any good evidence of flood plain fields in this area. Flood-plain fields (artificially watered) are present in the area today and we still believe were probably utilized in the past as well. One possible explanation lies in the fact that many flood plain fields, if they were located near the river, have been buried or otherwise obscured by the latest depositional cycle which began around A.D. 1450. We believe that this or another presently unknown variable was responsible for our not identifying such systems.

Generally speaking our information for systems in the Lower Sonoran Basin and Range Province is not as complete as for the two other sub-areas of the study area. This appears to be the product of two conditions: 1) Proportionately less ground truth activity was carried out in this region, and 2) there simply aren't as many systems. Without question the need to control water for cultivation purposes was as high or higher here than in the other two areas, but the natural environment set parameters, particularly topographically, that argued against the use of many types of systems that we noted

in the other areas. There may have been cultural factors working here as well; factors which are only very inexactly understood given the current state of our knowledge.

4.2.4 Summary

Although this project was an interdisciplinary undertaking, the focus of the most important questions being considered was the adaptations made by pre-Columbian man to the natural and social conditions that existed. Primarily for this reason the analysis and interpretation of the evidence for such adaptations rests primarily with the archaeologist. Results of the work done by other scientists on the project team have been presented elsewhere.

It was noted that although questions of culture history, the nature of cultural boundary systems, and the cultural interrelationships of the prehistoric population in the study area was of major import in our researches, they cannot at present be adequately answered. It would be necessary to answer four fundamental questions to analyze and interpret social or cultural variables.

1) What are the temporal placements of specific sites and systems?

2) What was the paleoenvironment like? What kinds of climatic conditions prevailed?

3) What sites are associated with what systems?

4) What are the interrelationships between sites and systems in the various sub-regions of the overall study area?

Our current inability to answer these questions fully has necessitated a slight alteration in our weighing of the importance of such variables. To compensate in some measure for the lack of a detailed cultural analysis six models of occupation and exploitation of the test area were presented. Clearly no one of these reflected cultural reality throughout the prehistoric occupation span. Our current best evidence indicates a shifting pattern of utilization of the area through time.

Prior to ca. 300 BC there is only scant evidence of human occupation in this area of central Arizona. Some sizable scatters of chipped stone, particularly in the southern transition zone and the Lower Sonoran Basin and Range Province may be indicative of bands of nomadic hunter-gatherers who exploited the general area and its resources during some portion of their yearly round. The techniques of cultivation were unknown to these people and they did not build any of the numerous water management/land use systems in the region.

From approximately 300 BC to AD 1100 the major exploitation of the test area appears to have been undertaken by the

peoples of the Lower Sonoran Basin and Range region. Evidence indicates that there was at least seasonal exploitation of the transition zone by these people (the Hohokam). It would appear that they continued up the Agua Fria to the vicinity of Dewey, Arizona. It is unclear as to whether they were also exploiting resources in the Mesa-Canyon complex outside the immediate environs of the Agua Fria. Exploitation of wild resources in this northern area would be expectable and indirect evidence of typical Hohokam designs on many petroglyph panels in the area of Perry Mesa lend impetus to this speculation.

Between AD 1100-1300 scanty evidence suggests a movement of some people not indigenous to the area into the transition zone. There is some data (architecture, general cultural assemblage, site location and layout) to suggest that these new people had moved into the area from the southeastern part of Arizona between AD 1100-1200. This would appear logical given the fact that the transition zone and many areas of southeastern Arizona (including the area around Tucson) are situated at similar elevations and have many of the same vegetation communities. Whoever these people were, they appear to be likely candidates for the building of the majority of the documented water management/land use systems in this sub-area. These people were also probably responsible

for the construction of many of the hilltop sites, such as Ariz. T:4:5 and most especially the large masonry site of Ariz. T:4:8.

For as yet inexactly known reasons the Hohokam appear to have ceased exploiting the transition zone during this period. Evidence indicates that they had retreated further south to their heartland. Seasonal exploitation of wild resources in the transition zone by the Hohokam may have been continuing.

Finally during this period an apparently separate group of people began establishing sites in the vicinity of the Mesa-Canyon complex. Their origins are obscure, but there is some evidence to suggest that they derive from areas north and east of the test area.

Between ca. A.D. 1300-1450 the situation perhaps changed again. During this time period the most intensive occupation of the Mesa-Canyon complex took place. We believe that most of the systems identified in this sub-region date to this period. Who, if anyone, was exploiting the resources of the transition zone at this time is not clear. Current evidence suggests that intensive occupation of the zone probably ceased during the early portion of this period. If the Mesa-Canyon complex was the homeland of as many people during this period as it appears that it was, there seems an excellent

possibility that people here would utilize already established systems elsewhere (transition zone). It is admittedly difficult to imagine such a sizable population subsisting entirely on what could be grown or gathered in such a restricted environmental setting as the Mesa-Canyon complex. It is unclear as to whether the people living in the Upper Sonoran area also ventured into the Lower Sonoran zone for subsistence resources. Certainly by the close of this period, if not before, the Lower Sonoran portion of the test area had been abandoned. By A.D. 1450 or shortly thereafter the entire study area had been abandoned by prehistoric peoples.

This cursory description of the culture history of the study area is speculative. It is presented as such but also to illustrate that many of the hypothetical models described and illustrated previously were a valid representation of conditions at different periods in time.

Due to our inexact knowledge of the area's culture history we concentrated within the frame work of our archaeological interpretation and analysis on the means by which populations in all three sub-areas utilized water management and land use systems for cultivating that portion of their diet consisting of domesticated foods. This perspective has allowed us to, in a sense, disregard the variable of temporal placement of sites and systems.

We wished to develop an organizing and explanatory mechanism that would be relatively free of temporal constraints and one which would allow us to take natural environmental parameters into consideration. We devised the concept of minimum expenditure systems that would have eventuated in a series of mini-max strategies specific to any of the three major sub-areas. We adopted, basically as an heuristic device, the Plog-Garrett model which was designed to measure the relationship between habitat and water management strategies. Through use of the assumptions of this model and our knowledge of our particular area, we were able to suggest that the distribution, size and type of water management/land use techniques would vary from sub-area to sub-area depending on natural factors (technology was held as a constant).

We could not use the model as a pure predictive device due to our inability to quantify certain key variables. These included prehistoric dedadic rainfall, yearly rainfall, and carrying capacity. Our analysis and interpretation of the archaeological remains has benefitted through use of this model and its underlying assumptions. We feel we have been able to isolate certain key variables in the natural environment which had to be closely evaluated by the prehistoric peoples prior to construction of given kinds of systems in given localities. In a semi-arid region such as the study area water availability

would immediately come to mind as one such variable. To a certain degree this holds true. For example, although only three trellis drainages were noted in the study area, none had evidence of human utilization through modification of the natural landscape (construction of systems). This pattern is notable, not because amounts of water in such networks would not be sufficient, but because trellis drainages tend to have channeling and runoff characteristics unsuitable for use in systems at this level of sophistication.

The amount of runoff water then, does not appear to have been a critical factor. The hydrologist has ascertained that there were substantial amounts of water available for both domestic and agricultural usage. What we have not been able to ascertain with certainty is whether or not the water hypothetically available was distributed at necessary and/or desirable times throughout the year. Precipitation and runoff distribution would have been even more critical in areas of the transition and Lower Sonoran zones in the event that the prehistoric farmers were engaged in double cropping. (cf. Bohrer 1970). Double cropping would not likely have been possible in the Upper Sonoran Mesa-Canyon complex. The admittedly inconclusive evidence we possess regarding the paleoenvironment would seem to suggest that a trend towards reduction in mean annual precipitation and/or a shift in rain-

fall distribution may have been a major element in causing the test area to have been abandoned prehistorically between A.D. 1300 and A.D. 1450.

In our analysis we determined that four major natural parameters appear to have been key determinants in the distribution, size and type of water management/land use systems employed: 1) drainage network geometry, 2) slope, 3) bedrock type, and 4) soil type and cover. The distribution of biological communities, particularly floral, does not seem to have been a natural parameter requiring changes in adaptional strategy. Such distribution was undoubtedly important as regards the potential exploitability of various wild species in a given sub-area, but was not of prime consideration in the decisions of where to place which types of systems.

One final comment. Throughout this section we have discussed only briefly the use of satellite imagery. There was one major reason for this. We have tried to emphasize throughout this document that we feel the potential uses of such imagery are very far-reaching. However, we have also had occasion to note that NASA imagery, primarily due to problems in resolution, was best applied in our project as a means for prediction. We could not actually identify specific sites and systems on the imagery. Taken in concert with the concept of minimum expenditure systems and the cost/benefit model, the

imagery has played an important role in our analysis. It has allowed a synoptic perspective necessary for an understanding of the natural (particularly topographic, geological and hydrological) conditions present in an entire area. It permitted predictions as to site and system location, and sometimes system type. These predictions were far from 100% accurate, but without having had the opportunity to make them and then field check the results, our understanding of the hydrology of prehistoric farming systems would have been substantially reduced.

5.0 CONCLUSIONS

Accuracy of Results and Their Wider Applicability

The wider applicability of the results obtained through the use and interpretation of satellite imagery by the Central Arizona Ecotone Project is discussed in relationship to other EREP investigations. CAEP was different from most EREP projects in that it was not oriented towards a single discipline but was rather a truly interdisciplinary endeavor. As a result of the melding of a number of natural sciences with the inexact social science of archaeology, data could not be interpreted in as much detail as in singular disciplines and results were not as easily quantifiable.

Theory and method in archaeological investigations of phenomona have seen great changes occur in the past 15-20 years. No longer is it feasible for the archaeologist to attempt to accomplish all the data collection and analysis himself. Rather there is a pronounced trend towards integration of results with other natural and social sciences. As increasing emphasis has come to be placed on the roles played by both the natural and social environments in the decision-making strategies of human groups, it has become necessary to employ a wider range of specialists in our investigations than was

thought possible and/or useful in the recent past. While single site analysis remains an important research focus for many prehistorians, the regional perspective has come to dominate the research interests of many archaeologists.

Adoption of the regional perspective, while greatly increasing our potential ability to analyze and evaluate the interdependence of social and natural parameters on the behavior of human populations, often poses serious logistical problems. Coverage of an entire region through use of only ground truth activities is impossible. Taking this as a given, the CAEP project team would suggest that the synoptic view offered by Skylab or other orbital remotely sensed data is most widely applicable in the formulation of research design and strategy. Data retrieved and interpreted from remote sensing enables the investigator to more efficiently allocate his invariably limited field time and labor. We feel strongly that the opportunity to perceive the various parameters of the natural environment and their articulations can lead to the formulation of explicit questions and the relationships which do or do not exist between the two. This is particularly true of, but not necessarily restricted to, problems which have as a primary focus the study of prehistoric settlement and subsistence systems and their relationship to environmental and sub-environmental zones.

5.1 EVALUATION OF REMOTE SENSING CONTRIBUTION

Although the particular results of our project in some cases fell short of our expectations, it is not necessarily indicative of the wider applicability of them specifically, or orbital imagery in general. Therefore we would speculate that the kinds of hypothetical applications of such information would fall into the following broad-based categories:

1) General Environment -- We know that data derived from the false color infrared photography and enhanced multispectral scanner imagery can be an important research tool for the student of biological boundary systems, as has been demonstrated by numerous studies. This is particularly true for the botanist, for although the false color infrared data we utilized in CAEP, most especially from SL4, was generally too homogeneous in hue to detect noticeable differences in the make-up of individual biological communities or zones, it could have great practical utility if imagery were obtained during the growing season. We feel that this would be particularly true in arid to semi-arid environments (cf. Gumerman and Lyons 1971; Gumerman and Neely 1972). However, recent research (Bruder et al 1975) has also shown the viability of false color infrared in delineating vegetational differences in tropical to sub-tropical areas (see also Coe 1974).

It has been shown (Gumerman and Neely 1972) that delineation of sub-environments through remotely sensed data can lead to a high degree of predictability of site type, size and location. Although most previous archaeological work in this area of consideration has been accomplished through low level interpretation, the exceptionally high quality of satellite imagery (particularly the resolution achieved in the S190B format) can be equally useful in predicting site location and size.

2) <u>Water</u> -- In our study area water availability and accessibility appears to have been an important variable in the initiation and accomplishment of prehistoric subsistence strategies. The ability to predict water resource accessibility can greatly assist the archaeologist in his efforts to identify and predict site type and location, or perhaps more importantly water control/agricultural system location and type.

False color infrared imagery taken during the growing season in arid to semi-arid environments indicates potential water sources by denoting varying degrees of plant vigor. In sub-tropical and tropical zones where water availability is not a problem but too much water can be, site predictability would be strengthened considerably by knowing areas where there were less swampy areas (Bruder et al 1975, Coe 1974).

3) Topography -- The ability to define and delineate topographic features is of great importance in the evaluation of prehistoric cultural resources. CAEP investigations indicate that of the number of possible natural constraints to site/size, location and type, topography is perhaps the most important. The Skylab data furnished topography information in great detail.

The factor of site/system predictability is considerably strengthened by imagery interpretation of topography. For example, in examination of two areas along the Agua Fria River archaeologists predicted site location and relative size with a high degree of accuracy by studying the topographic variable. Along the river from the Black Canyon City area to the Lake Pleasant Dam the river bed is relatively narrow and exhibits a high degree of relief adjacent to both banks. Through use of satellite imagery archaeologists predicted that if sites were to be found in this immediate vicinity they would be few in number and small in size. Similarly, in the region south of Lake Pleasant near Calderwood Butte the river opens into an area characterized by broad alluvial plains of low relief. In this instance, archaeologists predicted that ease of movement, fewer restrictions for site locations and the ability to utilize canal irrigation would indicate the presence of larger and more numerous sites and

larger water management/land use systems. Identification of site and systems through conventional aerial photography and ground truth activities indicated a high percentage of accuracy to these predictions.

Clearly the topographic variable will not always be as important in determinations of site and system location as it is in central Arizona. In areas moderate to high in relief, however, a synoptic view which allows for relatively easy interpretation would be an important application of the results of our project.

4) Drainage Network Geometrics -- The results of our project have wide applicability in the definition of drainage network geometry. The satellite coverage, from both S190 assemblies, allow for rapid identification of trellis and dendritic drainage nets. This attirbute is important when related to questions of prehistoric land utilization and water management. A major focus of our project has been to understand the interdependence of prehistoric population distribution and water source type. Although there are only three trellis-like drainage networks in the study area, archaeologists on the project team predicted that these would not be characterized by numerous sites and management systems due to the rapid runoff rates and channeling characteristics which would minimize the effectiveness of water control systems by

inhibiting sheet flow over large areas. No sites or systems were identified in either of the two trellis drainages checked through ground truth. Although the flow characteristics of drainage network may be more directly related to the materials in which the net is cut than to the geometry of the network, the opportunity to make predictions based on network geometry prior to the commencement of field activities is invaluable to the archaeologist asking questions similar to the ones we were asking.

5.2 RECOMMENDATIONS FOR APPLICATIONS

Better Utilization of Surface Water

A trip through the study area in Central Arizona today suggests the need for better utilization of surface water. In many sub-areas, most particularly in the transition zone and the Lower Sonoran Basin and Range complex, the observer is struck by the arid conditions and dessication of the landscape. Only near the Agua Fria does one note the characteristic green of land under cultivation. In the transition zone, where the Agua Fria is constricted on both sides by low hills and cliffs, this band of green is narrow and confined predominantly to the area around Black Canyon City. Today many acres of land are being cultivated in the Lower Sonoran Basin and Range complex. This has been made possible in large

measure through the damming of the Agua Fria and the concomitant creation of Lake Pleasant. Given the advancement of modern technology over that of the prehistoric peoples, this process (i.e., the damming of the Agua Fria) may have been the most efficient and useful way to utilize surface water in this semi-arid area.

It is notable that the area deriving the greatest benefit from the Lake Pleasant Dam is relatively flat (slope in most places does not exceed 5%). Maximal potential performances of irrigation systems (canals) is reached at slopes between 2% and 3% and irrigation is not an efficient means for utilization of surface water if slope exceeds 4-6% (Plog and Garrett 1973). The heavily dissected areas in the transition zone do not lend themselves to the construction of irrigation canals primarily because of the extreme fluctuation in the slope variable. Perhaps due to this reason very little farming of any kind appears to have been done in the area since prehistoric times. The area has long been used for grazing of livestock and today shows the dessication of the landscape often associated with such practices (grasses, thought to have once been a major constituent of the overall biological community are only currently present in severly restricted micro-environments). Overgrazing, in conjunction with a period of arroyo-cutting which appears to have begun at approximately

the same period, has led to near non-utilization of the transition zone for any purpose.

Through more efficient utilization of the available surface water at least two alternative uses could be found for land in the transition zone. Both are predicated on the adoption of water management techniques developed by the prehistoric inhabitants. Cultivation on a subsistence level could be accomplished through utilization of surface water using slope sheet wash, etc. It would appear that cash crops would not be a likelihood in this area without drastic measures being taken. To do so would mean adopting the aboriginal patterns, which appear to have been very efficient for these purposes. For example, an experiment was conducted during the spring of 1975 in the largest agricultural system near Ariz. T:4:8. After measuring the extent of the system of gridding and linear border alignments located in an area of varied slope the system was postulated as a flat plane. It was then calculated the percentage and angle of the slope had been a determining factor of the angle at which the rock alignments and borders had been set. Further investigation suggested that the prehistoric peoples were utilizing surface runoff from a water shed 3 to 4 times larger than in the area under cultivation. This pattern appears to hold for all but one system near Ariz. T:4:8 and may thus be applicable to

systems throughout the transition zone. There appears no reason to believe that such a pattern (although perhaps on a smaller scale) would not have direct applications in cultivation for subsistence, but not cash crop, purposes today.

A second, less easily substantiated, means of utilizing surface water through use of aboriginal patterning, concerns water for livestock. By analysis of the placement of prehistoric impoundment systems in the test area one could perhaps structure and locate such systems to impound water for modern cattle tanks. In particular, catchment basin-dam situations in some washes would help alleviate the necessity for drilling subsurface wells. This practice is common among the modern inhabitants of the town of New River and vicinity. Utilizing sub-surface water will result in a continued lowering of the water table, which eventually will make drilling such individual wells prohibitively costly.

Clearly, utilization of surface water through use of the aboriginal patterning is not a cure-all for problems of water availability and utility. Nonetheless, adoption of such measures would not appear to add to such problems either.

Control of Infiltration of Ground Water Supply

In general we do not feel that the results of our investigations allow for specific recommendations regarding the

control of infiltration of the ground water supply, in spite of the use of check dams and linear borders by the prehistoric inhabitants in their efforts along these lines. These systems, particularly in the alluvial areas of the transition zone and the Lower Sonoran Basin and Range complex, allowed for diversion of water from washes and steep slopes onto areas being cultivated. The combination of these techniques enabled these people to exert some control (mostly through the action of slowing down the diverted water) over the water's infiltration into the ground.

Efforts of these pre-Columbians to control such infiltration in areas where the surface is characterized by bedrock appear to have been less successful. It is notable, for example, that although there are many water control systems in the Mesa-Canyon complex, they tend to be smaller and more poorly defined than those systems associated with alluvial surfaces in the transition and Lower Sonoran zones. The Mesa-Canyon complex has only a very shallow soil cover overlying the faulted volcanic bedrock formations which include basaltic flows, tuffs and interbedded alluvium. On such areas precipitation tends to percolate immediately into the ground, allowing for only limited runoff, the infiltration of which is virtually impossible to control.

Preservation of Prehistoric Sites

It is difficult for us to recommend application of our results in the preservation of prehistoric sites. It is difficult due to our inability to identify sites from the satellite imagery. The imagery has allowed us, given the identification of the numerous natural variables, to predict where sites might be, but only through ground truth or use of low level imagery can we actually identify the existence of prehistoric sites in a given area.

At present in this area of the Southwest, preservation of prehistoric sites of less than monumental proportion is impeded by two major factors: increasing vandalism and the encroachment of urban areas into previously sparsely inhabited areas. There appears to be no way of halting the inexorable advance outwards of cities such as Phoenix. Our experience to date would suggest that chances of halting vandalism to sites appears equally remote.

Taking into consideration the element of prediction which the satellite imagery affords, this type of coverage could hypothetically be useful in limiting destruction of sites by urban encroachment. Our results indicate that through the analyses of imagery taken sequentially (i.e., at different intervals of time) the investigation could predict what types of sites are most likely to be destroyed. As our predictive

powers do not yet approach 100%, much of the analysis of sequential photos alone would not be useful without the concomitant use of ground truth (preferable) or low level aerial reconnaissance. Both processes combined could conceivably allow for the monitoring of the encroachment of urban and suburban development.

It seems somewhat unlikely that this process would be equally applicable to the problem of vandalism. However, this particular problem has reached epidemic proportions and any process that might alleviate such conditions would be a worthwhile endeavor. Unfortunately, in the case of vandalism, use of imagery, be it satellite, high level, or low level, would only allow for an assessment of damage rather than prediction or prevention. Although a potentially valuable tool in this regard, use of imagery to counteract vandalism has not yet enabled students of the past to even monitor such activity.

5.3 PROPOSED CHARACTERISTICS OF FUTURE REMOTE SENSING DATA

Theoretically on a world wide basis, the most advantageous type of remote sensing data from an orbital situation would be a camera system which produced Aerochrome infrared color imagery taken with a W-12 filter in a 5 x 5 inch format. Accompanying this and in the same format should be Aerial Color

High Resolution imagery taken without a filter. It is impossible to determine at present, due to lack of detailed analysis, but the multispectral scanning imagery might prove effective for archaeological purpose if the noise could be reduced or if computer enhancement for various environmental conditions was attempted.

An ideal secondary or complementary data collection system on a sub-orbital basis would be with the same type of film as well as standard panchromatic film collected at an altitude of no more than 65,000 feet. The complement of orbital and sub-orbital imagery collected under the right conditions could provide enormous benefit for the cultural environmental oriented archaeologist.

All imageries should be of sufficient resolution to enable 40x magnification without undue graininess.

The ideal seasons for collecting the data, especially the Aerochrome Infrared Color, should be during the fruiting of flowering seasons. This is especially important in arid and semi-arid regions but it is also a major consideration in temperate, tropical and sub-tropical regions. In tropical regions care should be taken to obtain the imagery in any format during the dry season in order to minimize the chances of obscuring cloud cover. It should be noted, however, that in many areas of the world during the dry season the slash and

burn type of farming system produces a smoke cover which is almost as detrimental to the investigator as natural cloud cover. Preferably the sun angle should be relatively low for all imagery formats, the data being collected no later than mid-morning or mid-afternoon.

5.4 PROPOSED TOPICS FOR FUTURE REMOTE SENSING STUDIES IN ARCHAEOLOGY

As noted before the liason between archaeology and aerial photography has increased appreciably over the last fifteen years (Gumerman and Lyons 1971). Greatly improving film types, cameras and sophisticated sensor data have multiplied the potential uses to which archaeologists can utilize the photographic medium. It has also become apparent that remote sensing, whether it be orbital or low altitude, will not solve such archaeological questions as site locality, site size and interrelationships without a more complete understanding of the medium by archaeologists than has to date been demonstrated. Archaeologists have often seen aerial photography as a panacea for all ills. It has been shown that indeed site location, water management and land use systems, and such unique features as roads, can be, many times, more readily discerned from aerial coverage than during ground truth operations. Nonetheless, the archaeologist must remember his

own and the medium's limitations while constructing his research design and requesting aerial photographic reconnaisance.

As shown in this report, specific types of orbital, and high altitude coverage are much more applicable for use than others by archaeologists. Keeping in mind recommendations made earlier for the use of such imagery, and the necessary use by archaeologists of an interdisciplinary approach to especially orbital data analysis, we would propose the following general environmental situations as appropriate localities for future study:

1) Semi-arid environments (i.e., the Desert Southwest, the Tehucan Valley, eastern and southeastern Iran, the Nazca Plain) represent ideal localities for the use of remote sensing data. As noted previously, color infrared coverage, like S190B, affords the archaeologist the opportunity to construct prediction models for site location, and hydro-agricultural systems throughout these regions. The typical sparse vegetation cover found in semi-arid environments likewise increases the probability of identifying individual land use and water management systems from high altitude or even orbital photographic coverage. Most importantly, however, remote sensing data supplies the archaeologist with a total picture of his entire test locality, which, for the localities mentioned, may not be adequately mapped. The archaeologist by an examination of the

coverage can delimit areas considered primary site resource localities, and reduce dramatically the amount of time he will spend in ground truth operations in what most researchers would consider a hostile environment.

2) Tropical regions (i.e., the west coast of Mexico, Yucatan) offer unique problems in their own right, yet afford the archaeologist a primary testing ground for remote sensing data use. In such areas vegetational patterning becomes the primary site indicator. If such localities can be identified prior to ground operations, the logistical problems created by jungle survey will be dramatically reduced.

As can be deduced from the geographical and environmental areas just suggested, general topics for further research center upon such questions as site locality prediction and land use/water management system identification. Additionally, however, in localities such as Chaco Canyon, New Mexico and southeastern Iran the mapping of the extensive communication networks of roads and pathways, which to date have been only fragmentarily identified, would be an ideal topic for the use of high-altitude or orbital data.

As Millon (1974) has demonstrated recently, the mapping of a large urban center such as Teotihucan can only successfully be accomplished using remote sensing data. Also, Old World archaeologists, working with problems of an ethnohistorical

nature (Ashe, 1967) have successfully used U-2 and lower altitude coverage to locate and ultimately excavate such features as Cadbury Castle.

It is virtually impossible for an archaeologist to propose general topics for future research in remote sensing. The discipline demands a degree of specialization which often negates the ability to randomly create broad, sweeping topics for consideration. The principal question asked by the Central Arizona Ecotone Project (how did prehistoric man adapt to the semi-arid desert of Central Arizona, and to what extent did his creation of land management and water control systems manipulate that environment) has applicability in many other geographical areas. Any given geographical area, however, will naturally have areal specific questions, and the practicality of utilizing remote sensing data in such areas must be carefully evaluated. We consider desert and jungle environments to be the most advantageous for the use of such mediums, and as to topics, that must be left to the discretion of the investigator.

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APPENDIX A

ARCHAEOLOGY FIELD SURVEY RESULTS

CENTRAL ARIZONA ECOTONE PROJECT

The archaeological survey carried out by the project team had as its main focus the location and description of archaeological sites and water management/land use systems. To this end, forms were utilized which required the recording of various specifically archaeological variables; for example, for each site a one or two word site description, i.e., habitation, special use, etc. Within these major categories a secondary set of descriptions was also recorded, e.g., cave/rock shelter under the category of habitation sites. Overall site size, kinds and quantities of artifacts present on the surface, and the number and kinds of structures and features present were also recorded -- as indeed they are in the majority of archaeological surveys.

Because of the nature of the information that was required to meet our project objectives, other categories of data were additionally recorded for each site located. Under a heading of "Social Environment" was noted the estimated percentage of arable land within a one km. radius. Natural environmental information was also recorded. This included the dominant plant communities on and around each site and those within one and five km. distances in all cardinal directions. It further included a description of land form, slope, vertical distance, and comments on drainages into the area.

Under the heading of "Water Resources," the following

was recorded for each site identified:

1) Drainage rank of closest major stream

2) Average drainage rank within 5 km. of the site

3) Permanence of nearest stream of rank three or above and the source of such information

4) Nearest water source type (stream, seep, etc.), its permanence and the source from which the information was derived

5) Permanence of other water sources within 1 km. of the site and the source of the information

6) Distance to other water sources from the site

In the upper Sonoran zone, a number of surveys were conducted in the Perry Mesa area, in the northeastern section of the test area. The concentration of survey effort was along and within the east-west trending canyon systems which drain into the Agua Fria River at the western edge of the mesa. Five different areas were surveyed in this portion:

1) Survey A was conducted in and around Baby Canyon, the northernmost of the canyon systems. Bishop Creek is the identifying drainage network. This was the shallowest canyon studied, maximum depth from rim to bottom being 72 meters. Both the northern and southern edges of the canyon were examined for a distance of one km. from the rims. The

KEY TO SUBAREA MAPS

SIZE OF SITE

- 1-2 ROOMS
- 3-5 ROOMS
- 6-10 ROOMS
- 11-15 ROOMS
- 16-30 ROOMS
- 31-50 ROOMS
- 51+ ROOMS

c CAVE

pp PETROGLYPH SITE

\+ SHERD SCATTER

⊕ LITHIC SCATTER

⑦ 1972 SURVEY, NO INFORMATION

AGRICULTURAL SYSTEMS

- LINEAR BORDERS
- TERRACES
- CLEARED LAND
- FLOODPLAINS
- CHECK DAM
- WAFFLE GARDENS
- CANALS
- MISCELLANEOUS

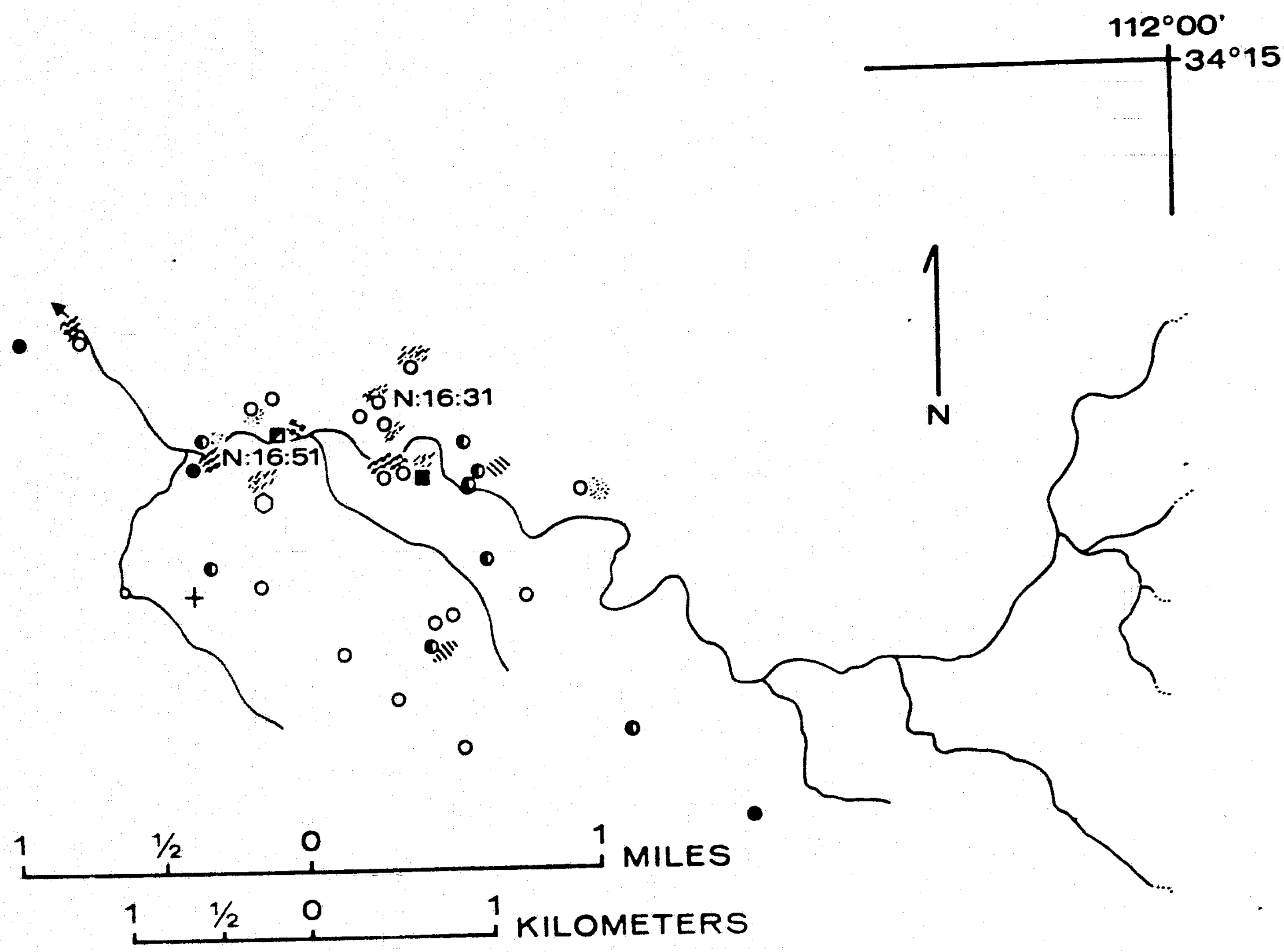
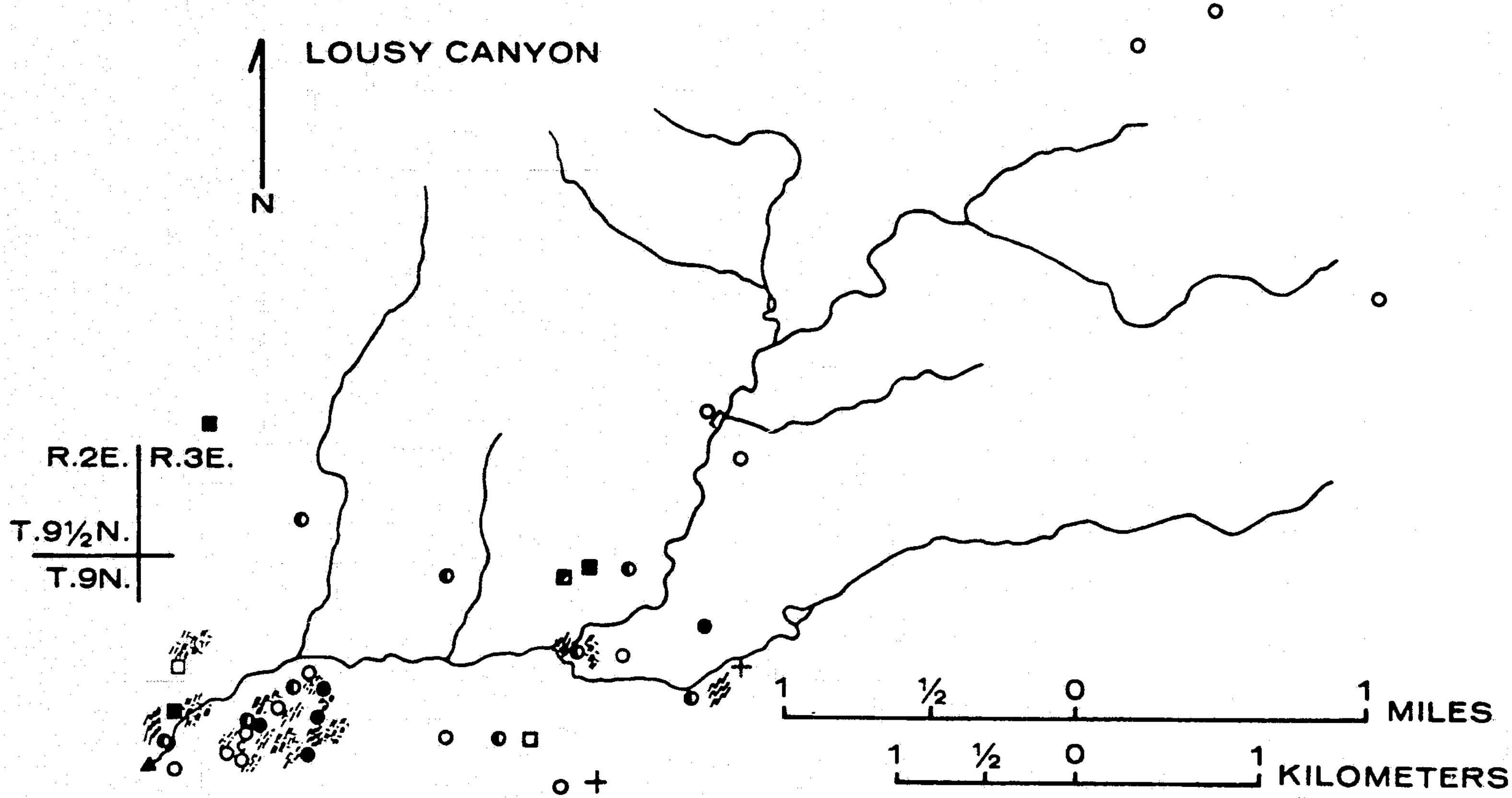


Figure A-1. BISHOP CREEK - BABY CANYON SURVEYED SITES AND SYSTEMS.



pp Figure A-2. LOUSY CANYON SURVEYED SITES AND SYSTEMS.

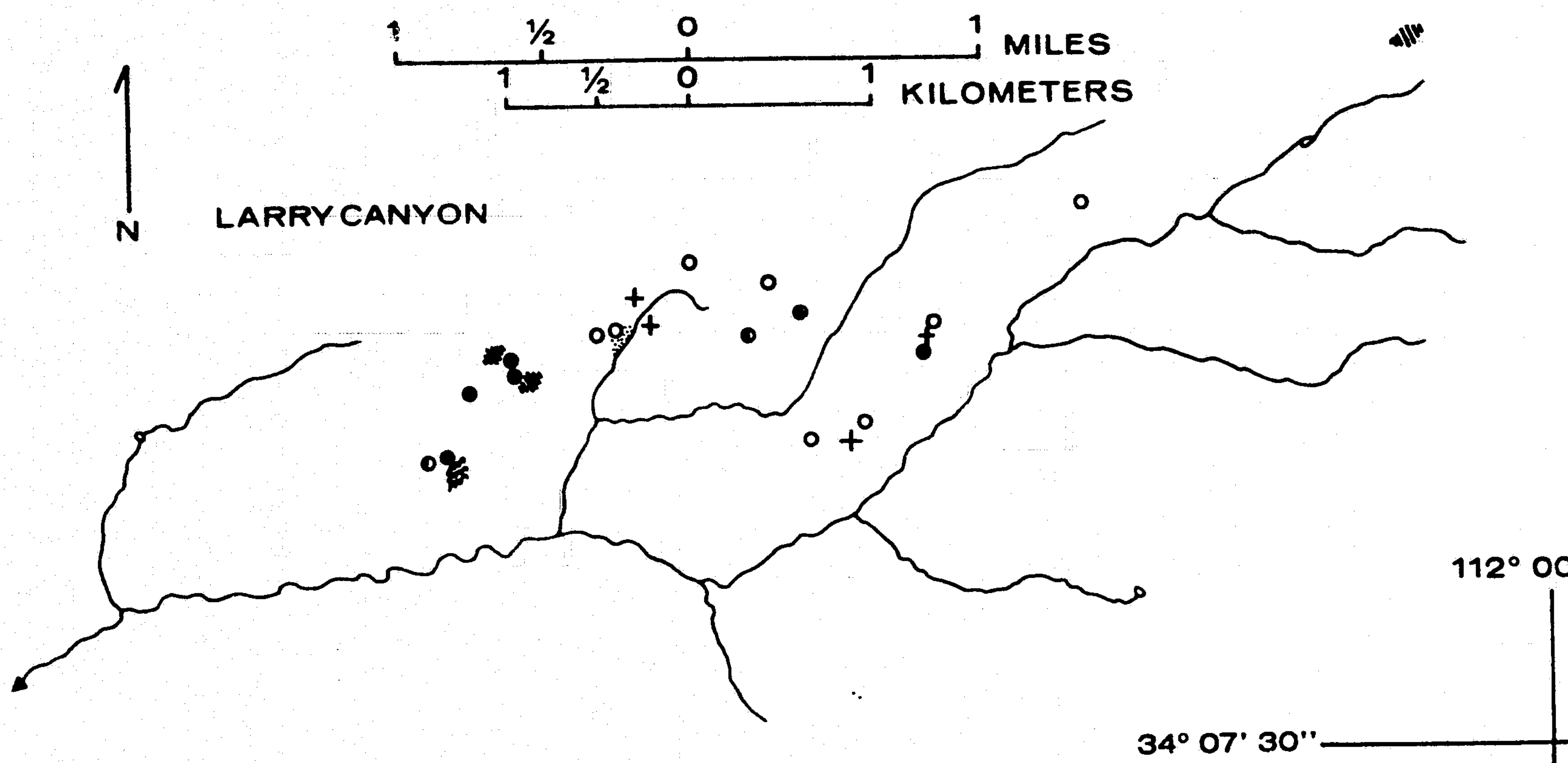


Figure A-3. LARRY CANYON SURVEYED SITES AND SYSTEMS.

canyon sides and bottom were also surveyed.

2) The Survey B area encompassed Lousy Canyon and its south and north rims. Lousy Spring, a perennial stream, flows in the bottom of the canyon, and due to this factor, archaeological survey was also conducted of the canyon mouth. Lousy Canyon is relatively steep sided and narrow and attains a depth of approximately 270 meters. The sides of the canyon are naturally terraced into three main levels, all of which were surveyed. The riparian community in Lousy Canyon was spectacular and provided the greatest ground-truth contrasts between riparian and non-riparian communities.

3) Survey C was carried out on the northern rim of Larry Canyon and the first terraces below the rim. Larry Canyon is very steep-sided, deep, and narrow. Survey was not conducted in the canyon bottom due to its inaccessibility.

4) Survey D covered the southernmost edge of Perry Mesa. It included coverage of New Boots Canyon, the southernmost of the canyon systems which dissect the mesa as well as the mesa-top along the southern edge of the escarpment.

5) Survey E covered two sections on the interior mesa-top. These sections were not associated with the east-west drainages. Survey was conducted here both as a control and to provide a sample from the mesa interior.

6) Additional survey carried out in the spring of

1975 was in the form of transects located along the southern edge of Perry Tank Canyon. These transects trended in a north-south orientation across the head of the canyon.

Four separate areas were originally surveyed in the transition zone. Additional survey was also carried out in this zone during the spring of 1975. Biological boundaries were also defined by a number of topographic features, including the southern rims of Black and Perry Mesa on the north, the foothills of the Bradshaw Mountains on the west, New River Mesa on the east and the town of New River on the south.

Survey area F was located in four sections along New River, a major drainage in the area. It was chosen for examination because of the high relief surrounding the drainage net itself. At the relative midpoint of this area was a hill-top masonry site (Ariz. T:4:5) which lies approximately 500 m. south of New River on an isolated butte. The site had initially been discovered during low altitude aerial reconnaissance of the transition zone.

Survey area 6 is southeast of Survey area F. It was also composed of four sections and has as an approximate midpoint the large hilltop masonry site (Ariz. T:4:8) (Figure A-5). This particular area was chosen for investigation for three major reasons:

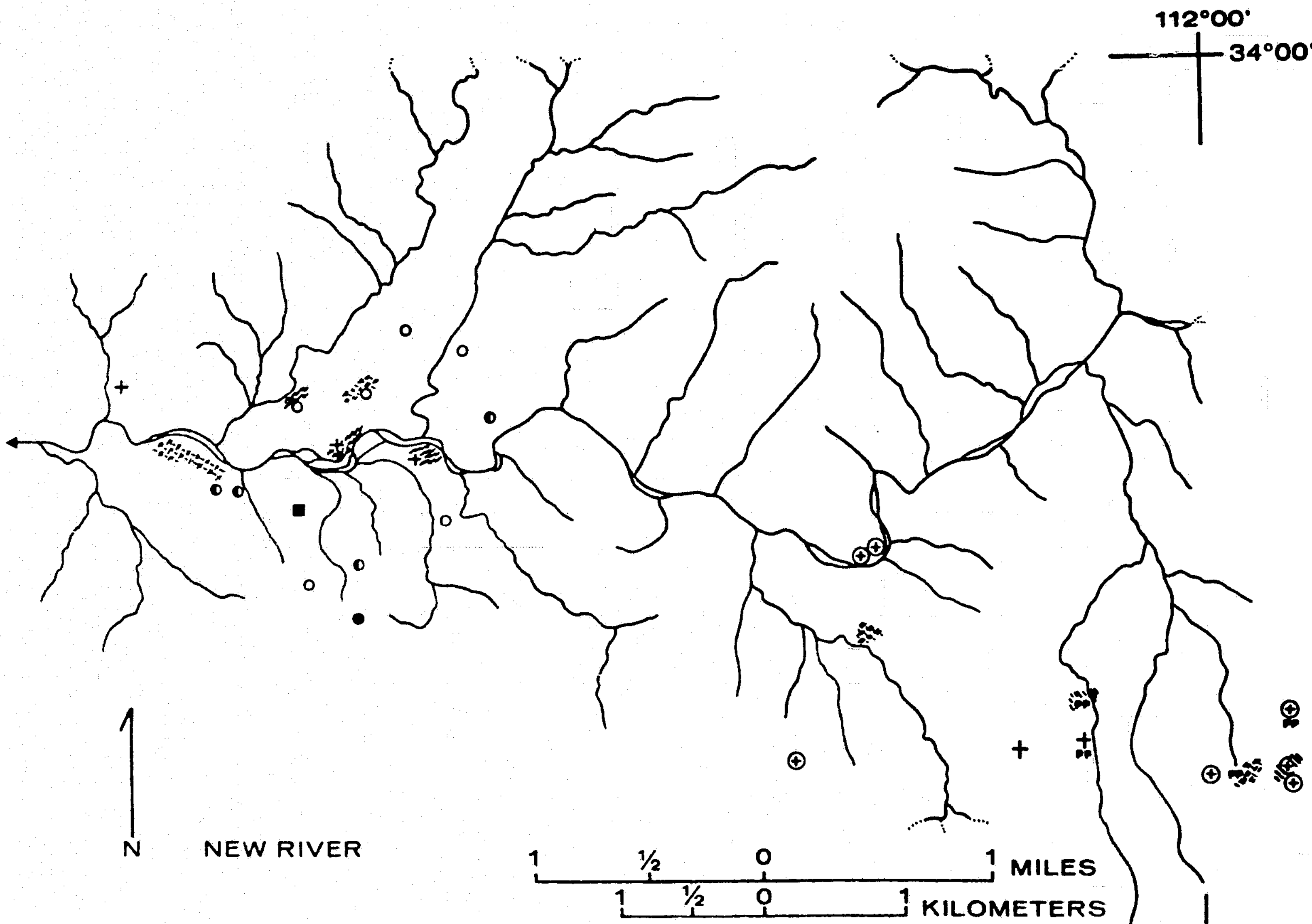


Figure A-4. NEW RIVER DRAINAGE SURVEYED SITES AND SYSTEMS.

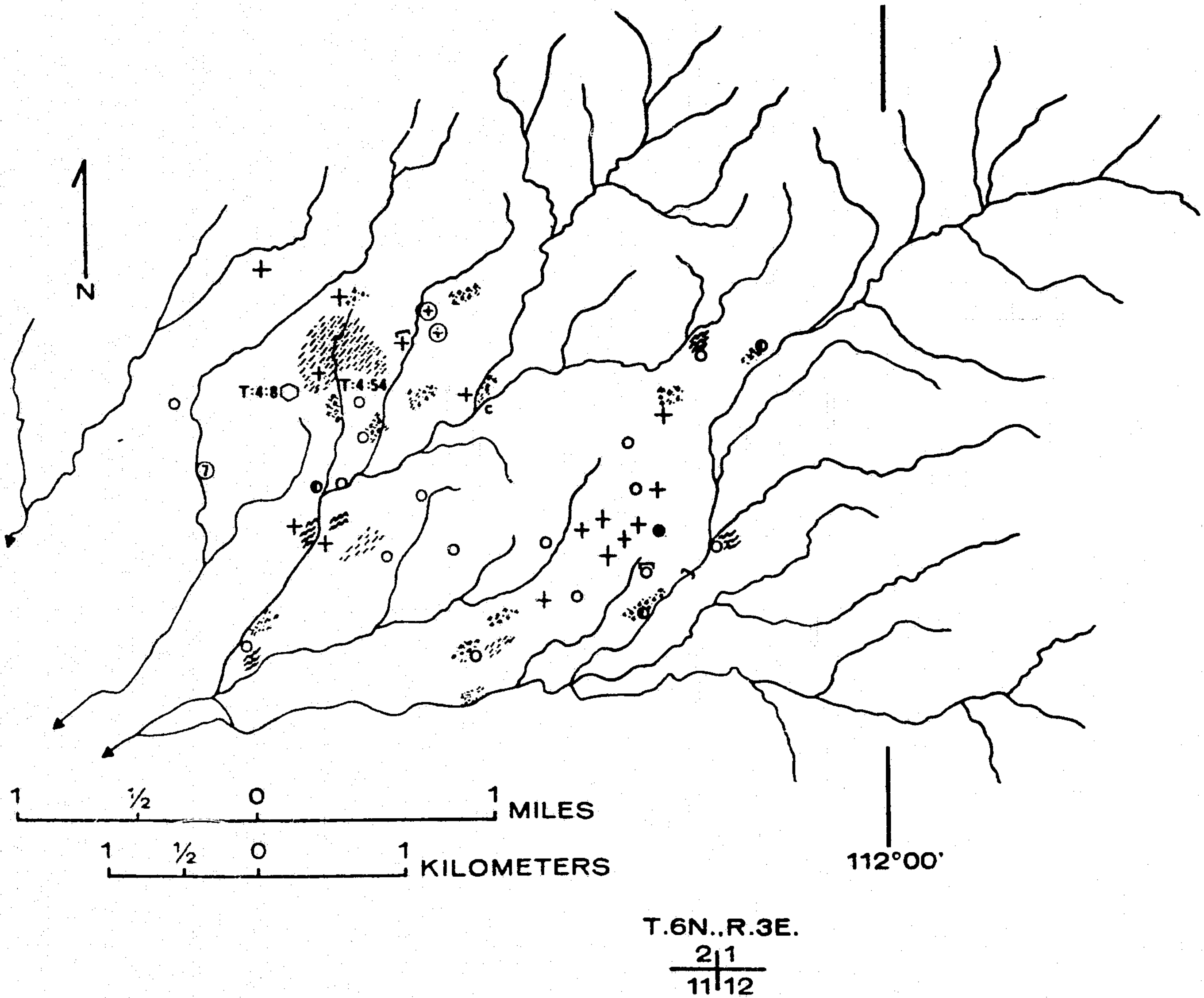


Figure A-5. AREA NEAR ARIZ.T:4:8 SURVEYED SITES AND SYSTEMS.

1) It encompasses a well designed dendritic drainage network.

2) It is in close proximity to major tertiary drainages such as Cline Creek.

3) It was felt that ground truth reconnaissance in this area would provide data regarding prehistoric lowland utilization in the region surrounding hilltop masonry habitation sites.

Survey H was conducted on Wild Burro Mesa, a relatively isolated topographical feature immediately west of the Agua Fria River. It was selected specifically because it is one of the few accessible highland localities in the transition zone.

Survey Area I was located in the foothills of the Bradshaw Mountains west of the Agua Fria. The area was centered along Soap Creek, a trellis-like drainage network. The area is almost totally inaccessible by foot or motor vehicle, but was selected for investigation because it represented one of the few deep cut trellis drainage nets in the test area.

Additional ground truth operations were carried out in the transition zone during the spring of 1975. Three transects were completed on New River Mesa, topographically

part of the transition zone. New River Mesa is the largest topographic feature between the Upper Sonoran Perry and Black Mesas and the lowland area of the transition zone.

As this transitional zone was a major focus of our research effort, the project team archaeologists felt that areas of ground truth reconnaissance should be representative of the major topographic, hydrological and biological divisions within it. Therefore, while the areas chosen for archaeological survey in this zone lie within generally close proximity to one another, they do cover all major natural environmental conditions within the area, and the collected data sets are therefore considered representative of the subregion as a whole.

The Lower Sonoran Zone in the test area extends south from the town of New River to Deer Valley. It is bounded on the west by the southern extensions of the Hieroglyphic Mountains and extends into the general area of Cave Creek in the eastern section. Lake Pleasant is an important modern feature of this portion of the study area. Ground truth activities within this general area were confined to the lower section of the Agua Fria River, below the Lake Pleasant dam and a trellis-like drainage network in the Hieroglyphic Mountains. Within this zone, both ground truth and low level aerial reconnaissance had been conducted by the Principal

Investigator prior to the inception of this project.

Survey area J encompassed three sections trending north to south along the first terrace on the eastern bank of the Agua Fria; Survey area K was located in the trellis drainage network in the Hieroglyphic Mountains. In the spring of 1975 additional archaeological survey in this zone was completed. This took the form of a transect located approximately three km. south of Lake Pleasant Dam. It was an east-west traverse through the foothills of the Hieroglyphics to the western edge of the Agua Fria.

Ground truth activities for archaeologists on the project team required more than simply covering specified areas on foot and recording the sites and systems. While it is possible to order the survey data in a temporal sequence, results tend to be highly generalized. Little micro-temporal control can be exerted over survey data unless numerous temporally diagnostic artifacts are present on each site. Further, micro-temporal control in our test area was, from the first, unlikely to be generated from survey data alone. We were, after all, examining an essentially unknown universe.

Although a control of the temporal nature of the remains was highly important in our research strategy, this alone does not completely account for our need for excavation data. Due to our interest in biological and social community

junctions, i.e., did they parallel one another or were they entirely disparate, we were interested in defining the formal structure of the sites in the three major environmental zones. Further we wished to define the nature of the cultural affiliations and their interrelationships from sub-area to sub-area, and finally, in defining the correlations between archaeological sites and prehistoric water management and land use systems. Because of many factors, then, it was necessary for the archaeologists to test selected sites by means of excavation.

Sites were selected for excavation which appeared from surface indications to be representative of the range of variability of sites noted in each of the major sub-areas of the entire test region. It was apparent from the outset that only limited excavation would be feasible given time and labor considerations. During the 1973 field season primary emphasis had been placed on archaeological survey. This precluded any work other than test excavations at a number of localities. Excavation at some sites was also precluded by another factor: the enormous amount of vandalism which has become increasingly predominant, particularly at the larger puebloan-like sites in the northern part of the test area.

Five sites were selected for test excavations during the 1973-74 field season. Three of them were in or near Baby

Canyon, and two were located in the transition zones. No excavation was carried out in the Lower Sonoran portion of the test area. We knew that other investigators had carried out excavation in this area previously and their data was available to us.

Additional excavation was carried out in the spring of 1975. During this period our efforts concentrated on a large, hill-top masonry site in the lowlands of the transition zone and a rockshelter in the Lower Sonoran zone, west of Lake Pleasant.

Following is a brief description of each site tested through excavation. Details of the excavations procedures, artifact counts, etc. are available upon request (see also Appendix Figures A-1, A-2, A-3, A-4, A-5).

Upper Sonoran Zone

1) Ariz. N:16:31

This site is located in a basalt boulder field on the north rim of Baby Canyon on Perry Mesa. The site is composed of three contiguous rooms, with a small terrace immediately to the south of these rooms. One room (the middle room of the three) was excavated. Test trenches were dug in the southern terrace and in an open "plaza-like" area north of the roomblock (Figure A-6).

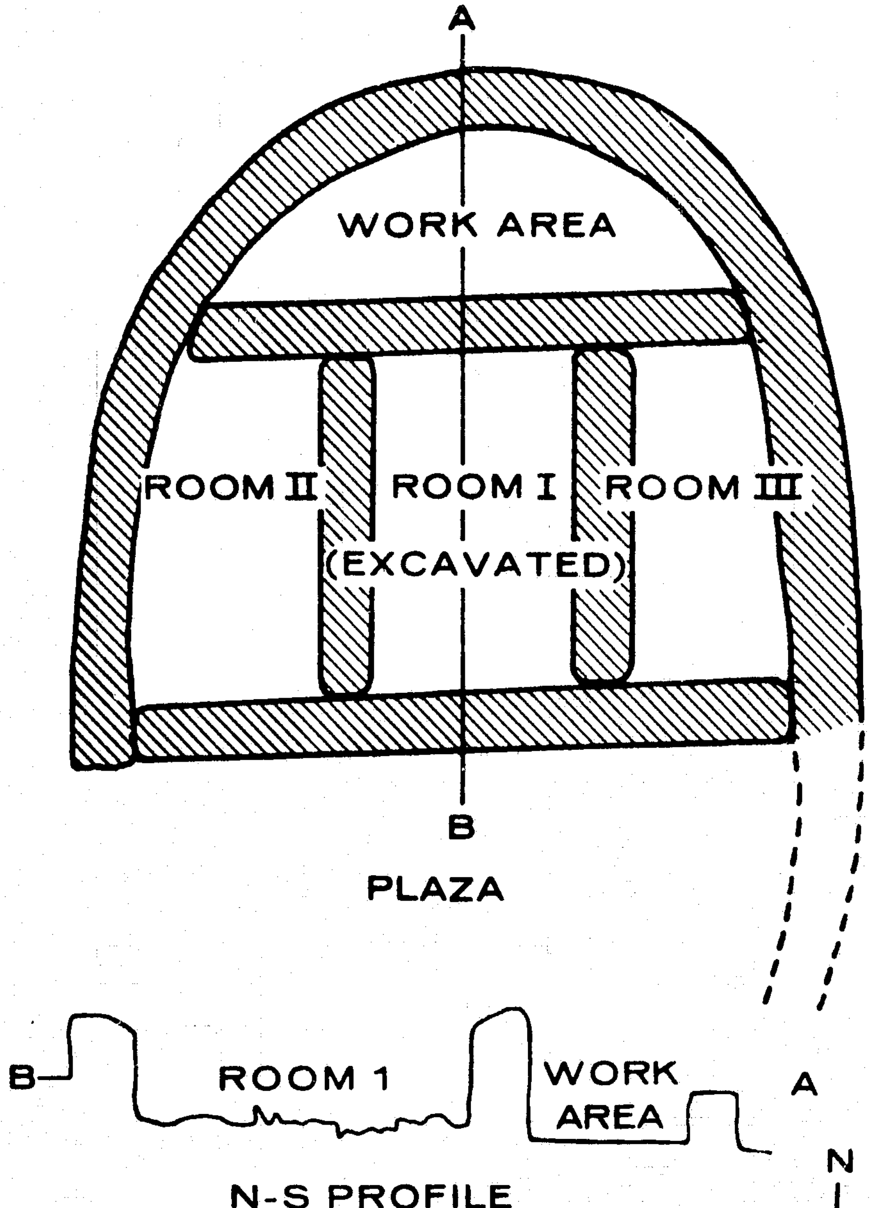


Figure A-6.
ARIZ. N:16:31
SCALE: 1CM=1METER

2) Ariz. N:16:51

This site is located in the bottom of Baby Canyon on the first alluvial terrace north of Bishop Creek. On the south slope of the canyon and on the south rim immediately above the site is a 70-90 room pueblo with associated land use systems. The site is composed of 19 rooms distributed between two plaza compounds. Three rooms were excavated, one in the smaller of the two compounds, two in the larger (Figure A-7).

3) Ariz. N:16:46

This site is located on the south rim of Baby Canyon, on a promontory jutting out from the rim into the canyon. It is directly southwest of Ariz. N:16:31. Four distinct architectural units were identified on the site. Unit I is a large enclosed plaza. Immediately to the north is a forty room pueblo (Unit II). North of Unit II on a lower level of the promontory is a 30 room pueblo (Unit III). Units II and III are connected by two small walled plazas. Unit IV is a small rock shelter off the east side of the promontory. Excavation at Ariz. N:16:46 was confined to the rockshelter, as the possibilities for preservation of such items as bone, woven materials, feathers and non-artifactual material (e.g., seeds) would be high.

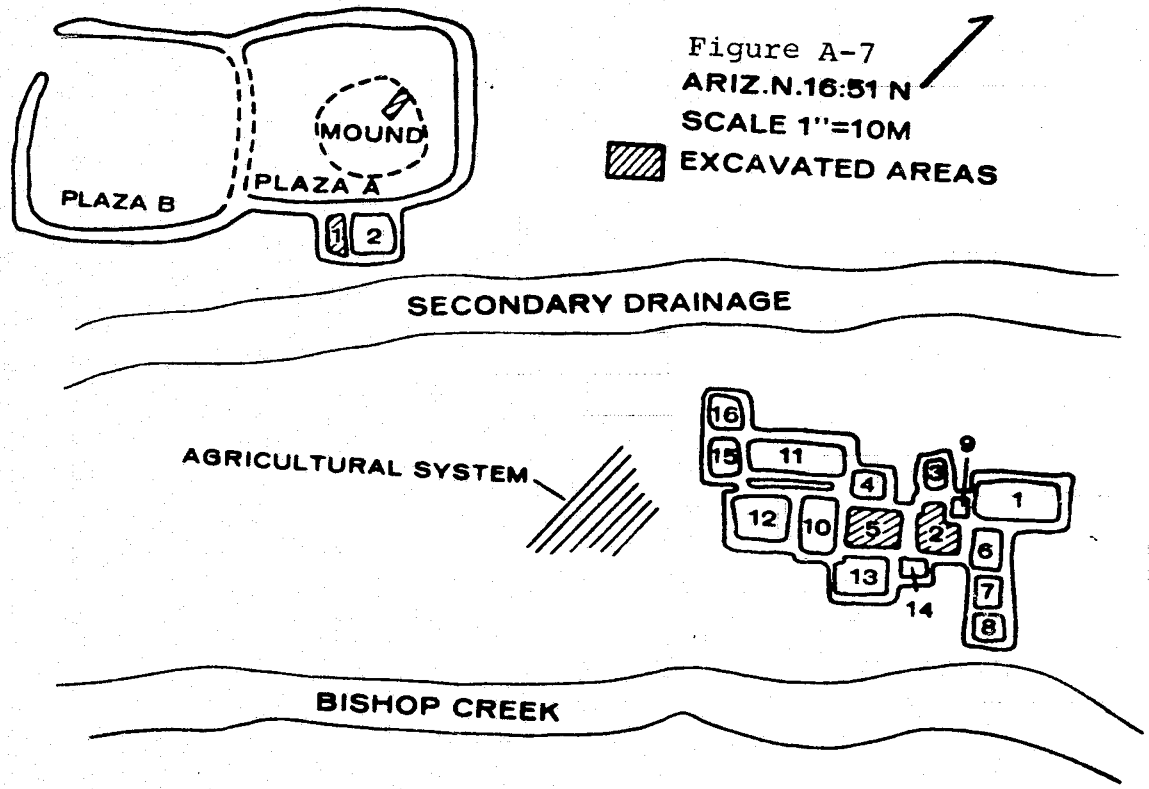


Figure A-7
ARIZ.N.16:51 N

Transition Zone

1) Ariz. T:4:5

This site is located off the western escarpment of New River Mesa, approximately one half km. south of the New River on an isolated butte 400 feet above the desert floor. It commands a view of at least three other hilltop masonry sites in the transition zone. The site is composed of thirteen semi-isolated rooms. Two rooms were excavated. As this site was difficult of access on foot, both people and equipment had to be helicoptered in and out (Appendix Figures A-8 and A-9).

2) Ariz. T:4:8

Excavations at this site were conducted during the spring of 1975. It is the most complex site tested by the project. The site is a large (87 rooms) hilltop masonry "pueblo" located approximately 8 km. east of the town of New River and approximately 2 km. south of the southern edge of New River Mesa. The cultural features are located in various places on the northern and eastern sides of the hill and include masonry room blocks, isolated rooms and open areas (plazas or courtyards) which are thought to have been the scene of numerous outdoor activities. Some rooms occur on the naturally terraced south side of the site. Features on the north slope occur on a series of artificial and natural

Figure A-8. Ariz:T:4:5-aerial view looking west

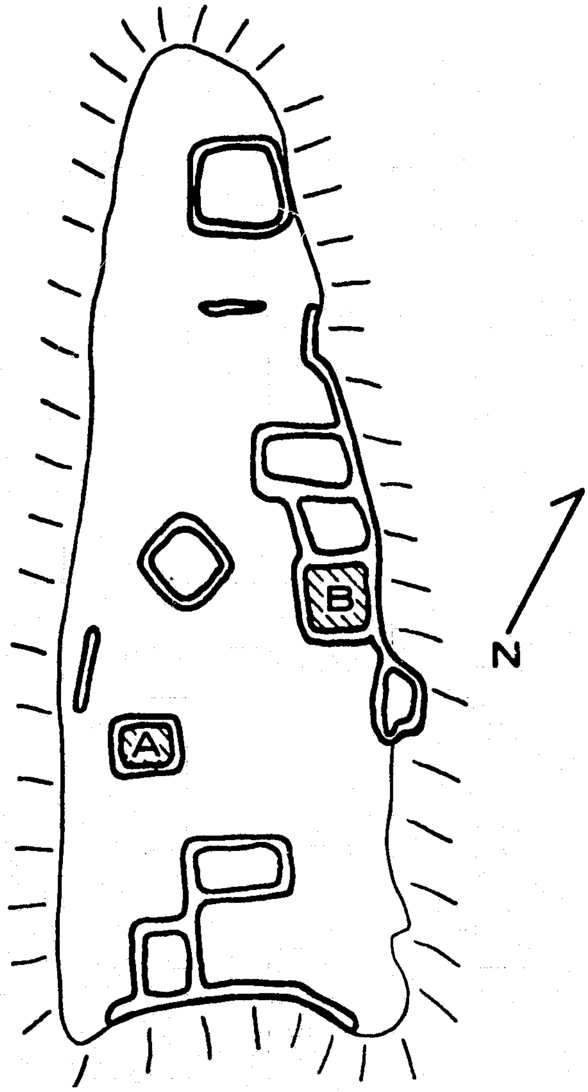
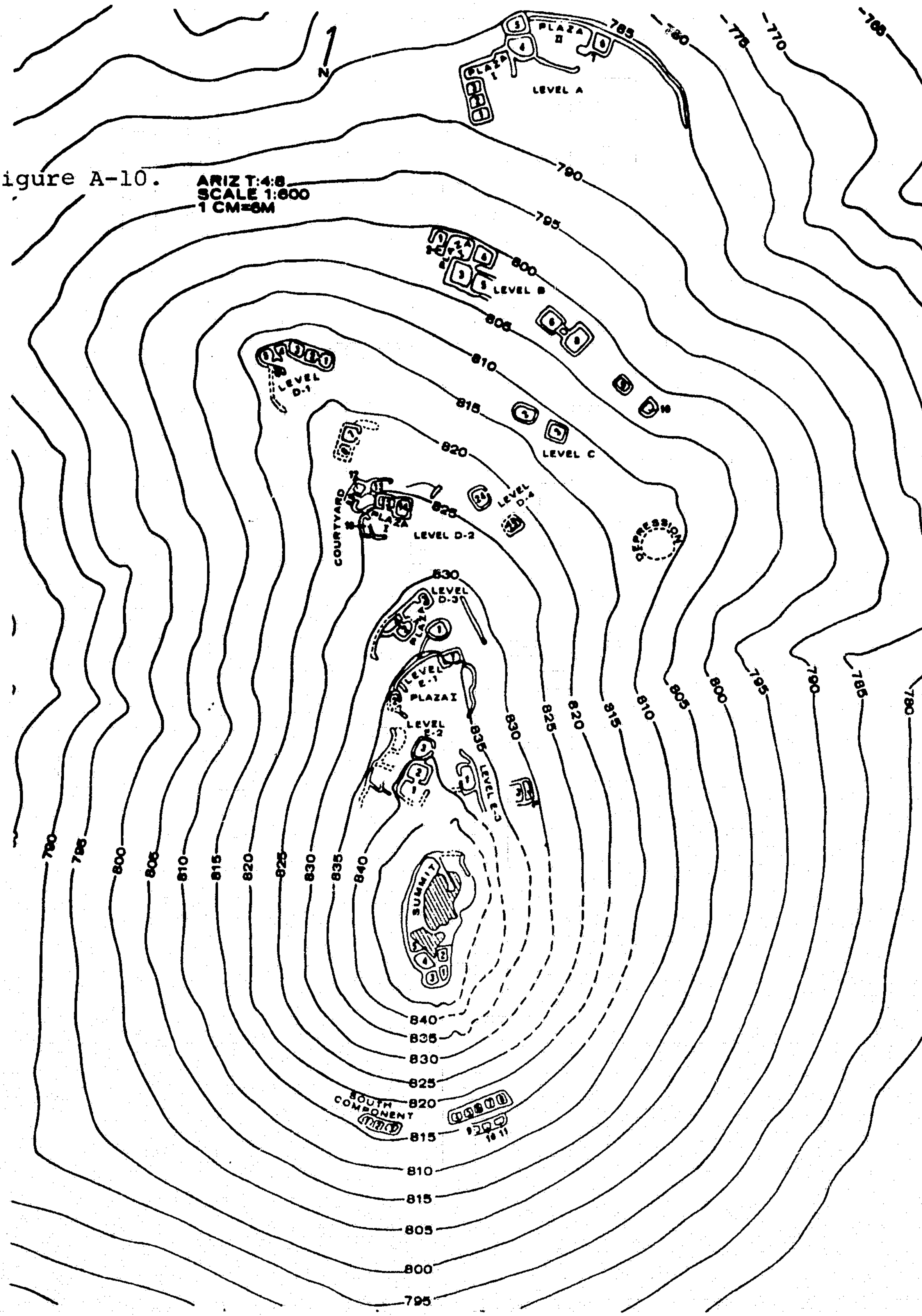


Figure A-9. ARIZ.T.4:5
SCALE 1"=10M
EXCAVATED

Figure A-10.


ARIZ T:4:8
SCALE 1:600
1 CM=6M
N
PLAZA II
PLAZA I
LEVEL A
LEVEL B
LEVEL C
LEVEL D-1
LEVEL D-2
LEVEL D-3
LEVEL D-4
COURTYARD
PLAZA I
DEPRESSION
LEVEL E-1
PLAZA I
LEVEL E-2
LEVEL E-3
SUMMIT
SOUTH COMPONENT

terraces. The lowland areas surrounding the site contain numerous water management/land use systems. Thirteen rooms and three plazas were wholly or partially excavated (Appendix Figure A-10).

3) Ariz. T:4:54

The site is located in the alluvial flats north of and at the base of Ariz. T:4:8. Associated with it are several acres of water management/land use systems. The site is a large sherd and lithic scatter with associated trash areas. Excavation consisted of three test trenches, two in the trash areas and one in association with an isolated linear border within the site boundaries.

Lower Sonoran Zone

1) Ariz. T:3:16

This site is a small rock shelter located southwest of Lake Pleasant, approximately 4 km. west of the Agua Fria River. There appear to be no other sites in the immediate vicinity.

APPENDIX B

DETAILED RESULTS OF DRAINAGE BASIN IMAGE INTERPRETATION

This first section, "Imagery: Comparisons with Ground Truth," differs from the second in that it consists of analyses that have been checked by field reconnaissance. In the illustrations that accompany the discussion, at least a portion of the total drainage basin map, as prepared from 7½ minute topographic quadrangles, is included to locate the specific areas viewed. In those sections labeled "specific observations," the numbers associated with each are keyed to numbers placed on the accompanying figures.

Imagery: Comparisons with Ground Truth

Basin 7 (Appendix Figure B-1):

Comparisons:

U-2 frame 7581 (zoom stereoscope with stereopair; drawn on mylar overlay over frame 7581)

Skylab frames 230 and 231 (zoom stereoscope with stereopair; drawn on mylar overlay)

Note: The entire basin was drawn as completely as possible using the above frames.

Specific Observations:

1. The wash shown on the Skylab frame is here but shorter than what was drawn; it is a second-

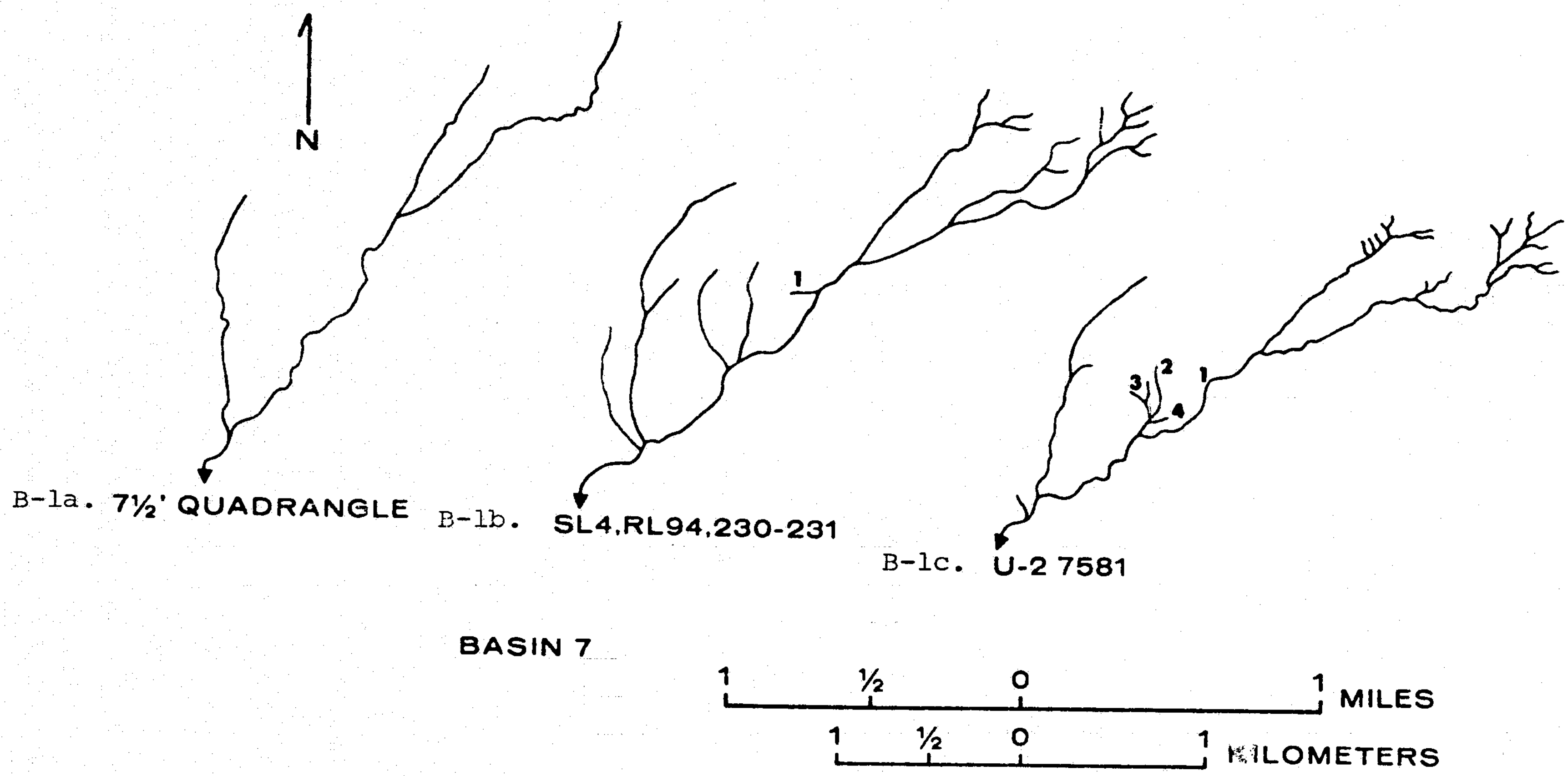


Figure B-1. THE DRAINAGE NETWORK OF BASIN 7 AS SHOWN BY THE SOURCES INDICATED. THE ENTIRE BASIN NETWORK IS SHOWN. SMALL NUMBERS ON THE NETWORKS SHOWN IN FIGURES 28b AND 28c (AND ON SUCCEEDING FIGURES) REFER TO SPECIFIC OBSERVATIONS NOTED IN TEXT.

order wash. Its depth and width (about 15 feet and 30 feet, respectively) are so great that missing it on the U-2 frame is inexplicable.

2. U-2 frame misses, typically, first-order rills, locally some second-order rills.

3. The Y-shaped net is shown well by the U-2 frame and is easily located on the ground; only weakly developed, non-integrated, single, short rills weren't seen in the northeast fork.

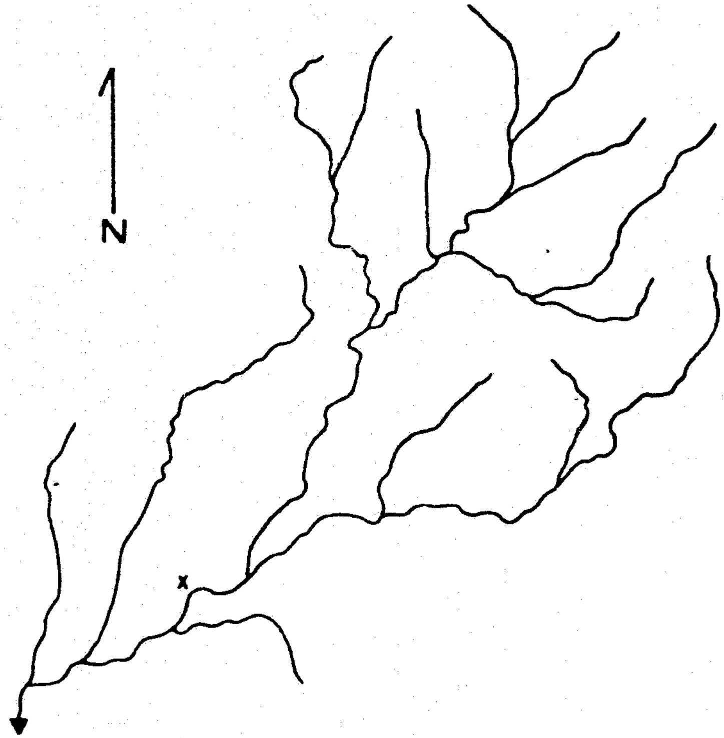
4. A network of washes and rills that join the one drawn are found here, but curiously were not visible in the U-2 frame.

Comments: Prior to drawing those renderings of the drainage network that were made, the following Skylab frames that covered this area were examined and rejected as useful sources of information: SL4, RL5B, #36-37; SL4, RL69, #106-107, SL4, RL70[1], #106-107, SL4, RL70[2], #106-107. It should be noted that the S-190B photography was the only Skylab photography deemed useful here.

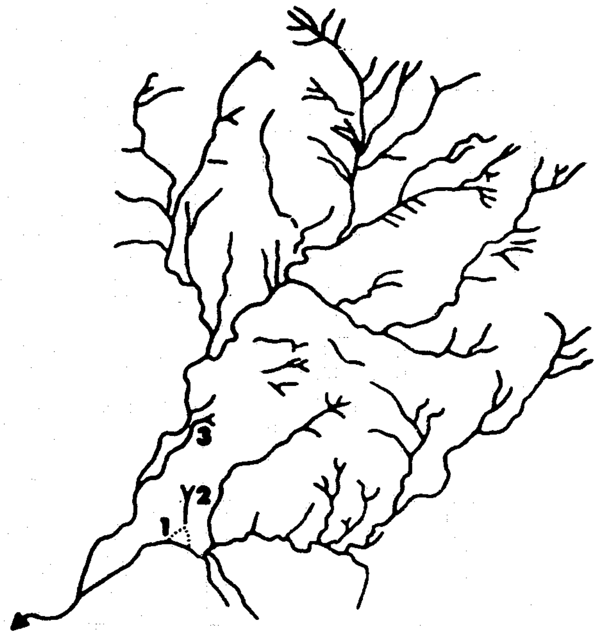
Basin 9 (Appendix Figure B-2):

Comparisons:

U-2 frame 7581 (zoom stereoscope with stereopair; drawn directly on photo 7581).



B-2a. 7½' QUADRANGLE



B-2b. U-2 7581

BASIN 9

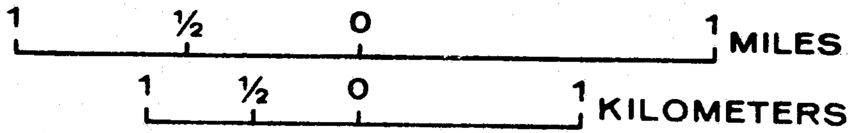


Figure B-2. THE DRAINAGE NETWORK OF BASIN 9 AS SHOWN BY THE SOURCES INDICATED. THE ENTIRE BASIN NETWORK IS SHOWN IN FIGURE 29a; 29b SHOWS ONLY THE PORTION UPSTREAM FROM POINT "X" MARKED ON 29a.

Specific observations:

1. The "fan" drawn is alluvium of the main stream chiefly, and is fan-shaped, but not a true fan; the drainage for the tributary is on the northwest side of this feature, and was not discriminated.

2. The U-2 frame saw this well; the fork is seen even though the tributaries are no more than about two feet deep; one additional order of very poorly defined rills was not seen via the U-2 frame.

3. The "braid" seen in the main stream is not part of the main stream, rather it takes the drainage of the two tributaries sketched and immediately to the north.

Comments: A comparison between the details shown in Figure B-2a and B-2b shows how much the U-2 photograph adds to the picture provided by the topographic map.

Basin 14 (Appendix Figure B-3):

Comparisons:

U-2 frame 7579 (zoom stereoscope with stereopair; drawn on mylar overlay over photo 7579)

Skylab frame 230 (zoom transfer scope only)

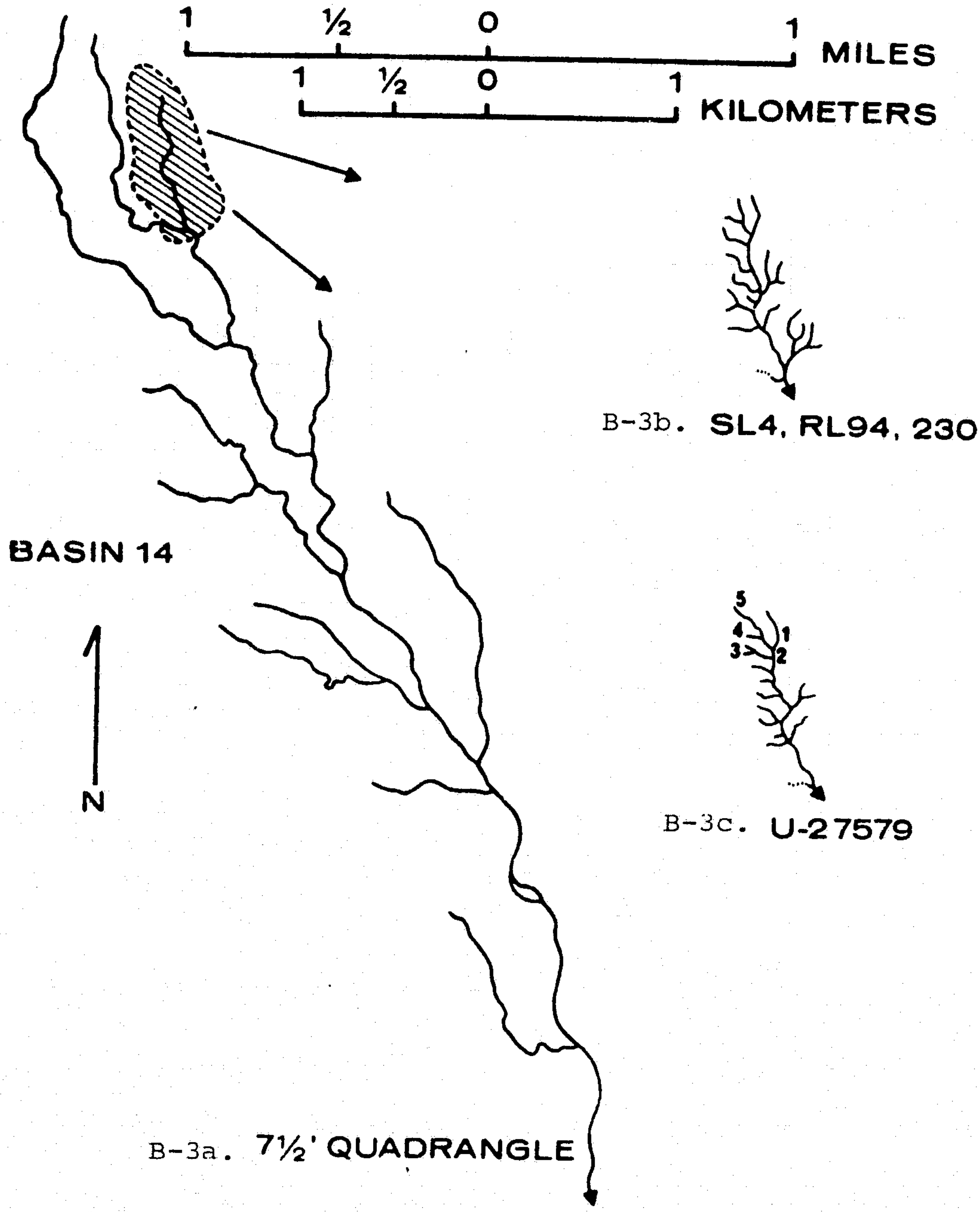


Figure B-3. THE DRAINAGE NETWORK OF BASIN 14 AS SHOWN BY THE SOURCES INDICATED. THE ENTIRE BASIN NETWORK IS SHOWN IN FIGURE 30a, 30b AND 30c SHOW ONLY THE AREA INDICATED IN THE HEADWATER REGION OF 30a.

Specific Observations:

1. Both the U-2 and Skylab missed very little; one order of shallow rills, largely not integrated with the main net were missed; the slopes are relatively steep here (1 foot vertical change in 5 feet horizontal change).
2. Some clear, first-order rills not seen by either U-2 or Skylab.
3. U-2 saw this exactly except the northernmost fork, which splits once again, adding one more order. Skylab missed this latter split as well as the southernmost fork seen by U-2.
4. U-2 and Skylab missed short, but well-defined first-order rill.
5. Mostly first-order, but a few second-order rills missed; most are relatively shallow but a few are 5 to 6 feet deep. Note that Skylab did not see the full length of this tributary.

Comments: In this area of relatively steep slopes, exposed bedrock, and relatively sparse vegetation, the information obtained from both formats is excellent, with the U-2 holding a slight edge.

Basin 15 (Appendix Figure B-4):

Comparisons:

U-2 frame 7579 (zoom stereoscope with stereopair; drawn directly on frame 7579)

Specific Observations:

1. U-2 typically missed second-order rills, occasionally third-order rills into the net drawn. The relief is very low, however; none of the rills observed as missed were greater than 3 feet in depth.
2. Only first-order rills are missed.
3. Up to two orders of rills are missed here.

Comments: The entire area checked is one of low relief and gentle slopes (1 foot vertical change in 20 feet horizontal change is representative). The rills not seen via photography typically measure a few to several tens of feet in length.

Basin 17 (Appendix Figure B-5):

Comparisons:

U-2 frame 7580 (zoom stereoscope with stereopair; network drawn on mylar overlay)

Specific observations:

1. A second-order, shallow (1 to 2 feet deep) rill system not seen.

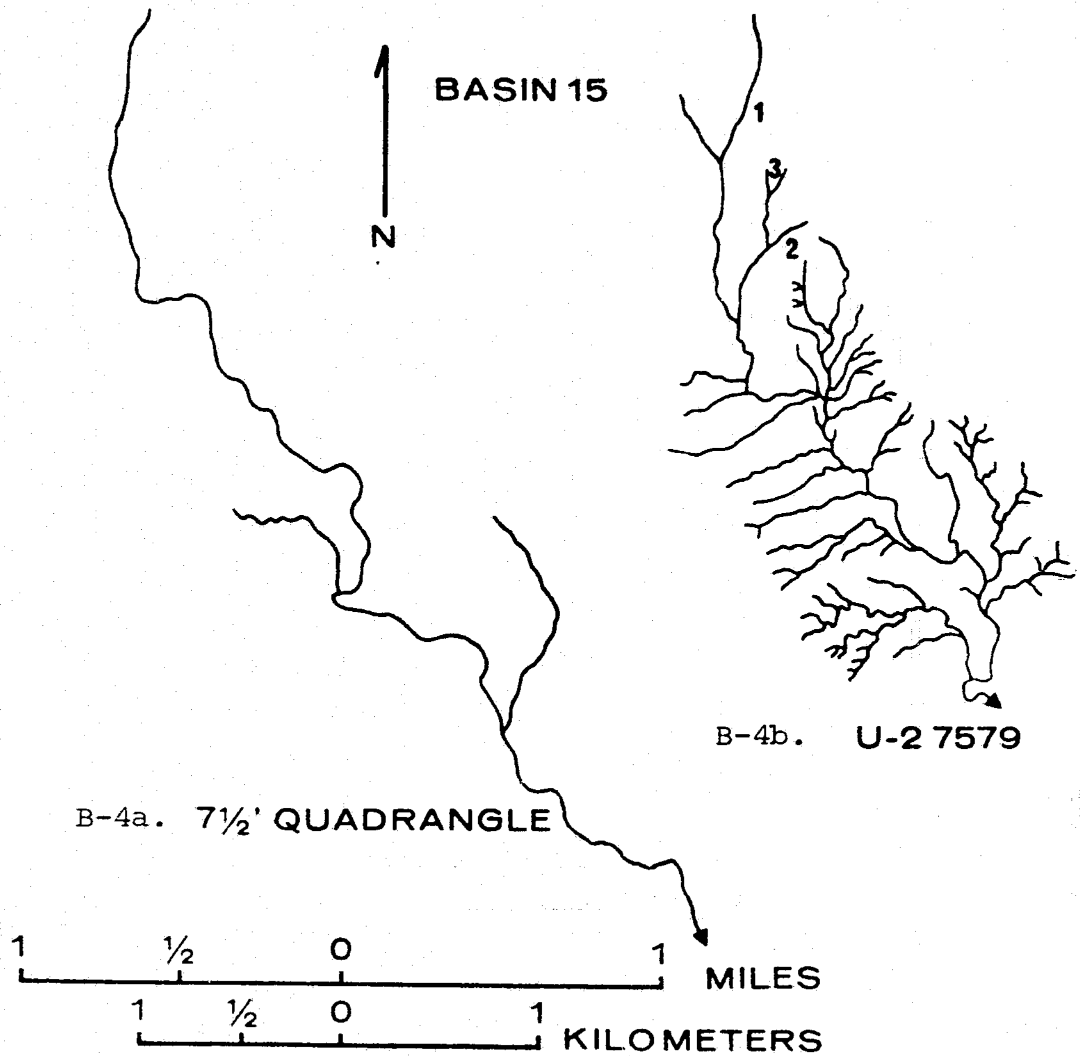


Figure B-4. THE DRAINAGE NETWORK OF BASIN 15 AS SHOWN BY THE SOURCES INDICATED. THE ENTIRE BASIN NETWORK IS SHOWN IN FIGURE 31a : 31b SHOWS THE PORTION UPSTREAM FROM POINT "X" MARKED ON 31a.

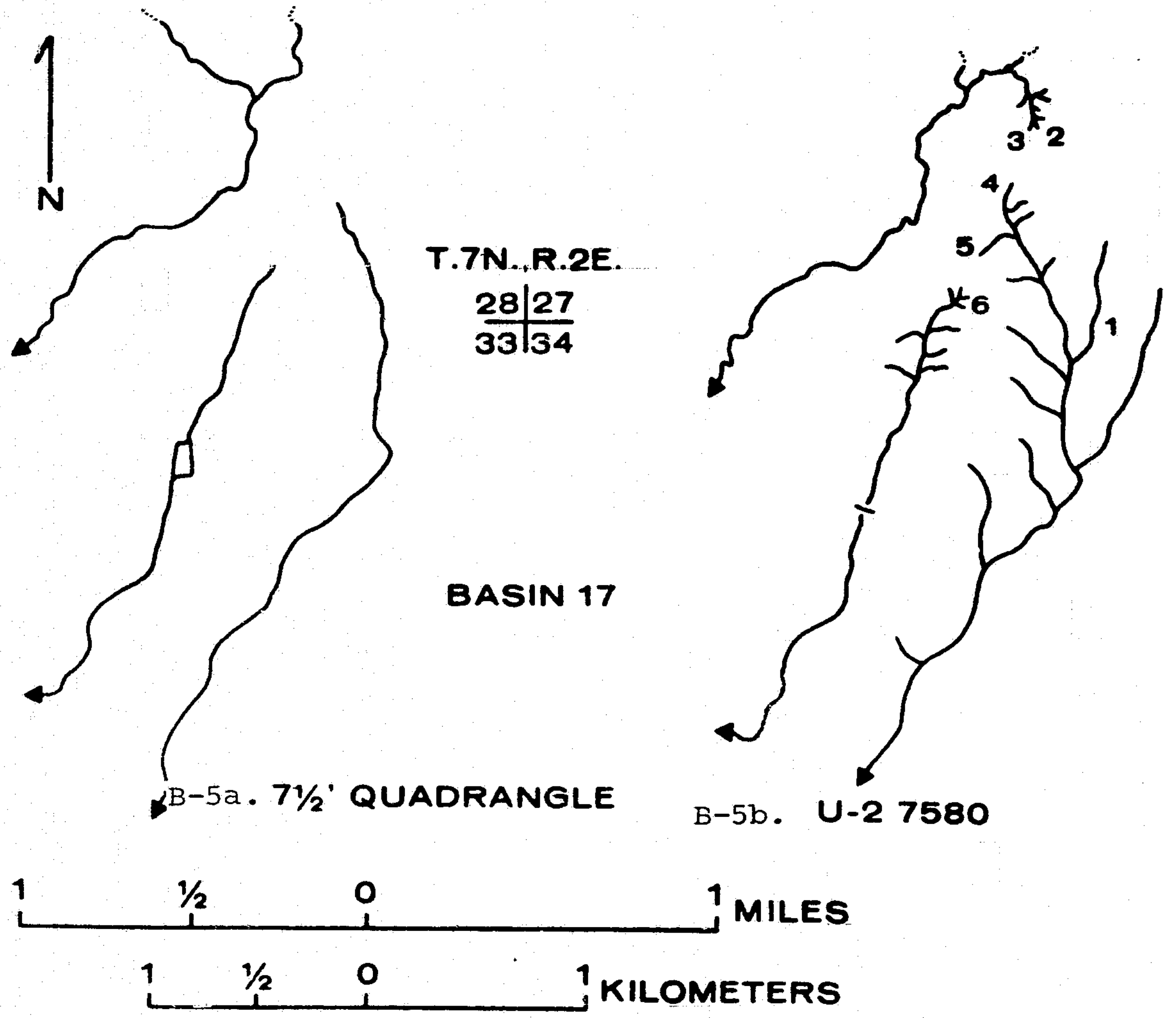


Figure B-5. THE DRAINAGE NETWORK OF BASIN 17 AS SHOWN BY THE SOURCES INDICATED. FIGURE 32a. SHOWS A PORTION OF THE HEADWATERS REGION OF THE BASIN WITHIN THE NEW RIVER 7½ MINUTE QUADRANGLE (SECTION CORNER INCLUDED FOR LOCATION PURPOSES).

2. U-2 caught all of this.

3. At the tip of this tributary, two orders of relatively short (40 to 50 foot length) rills were missed.

4. In this area, up to three orders of rills were missed; difficult to understand why because the third-order, at least, is fairly conspicuous.

5. This was exactly as drawn; no rills enter it.

6. These tributaries show up well, but the southeasternmost wash of this cluster of four actually has its mouth farther downstream, and is a second-order element.

Basin 19 (Appendix Figure B-6):

Comparisons:

U-2 frame 4922 (zoom stereoscope with stereopair; drainage net drawn directly on frame 4922)

Skylab frame 63 (zoom transfer scope only)

Specific Observations:

1. The U-2 showed everything, no orders missing.

2. Two first-order tributaries were missed. In the area of points 1 and 2, Skylab shows two washes, but they were not located well.

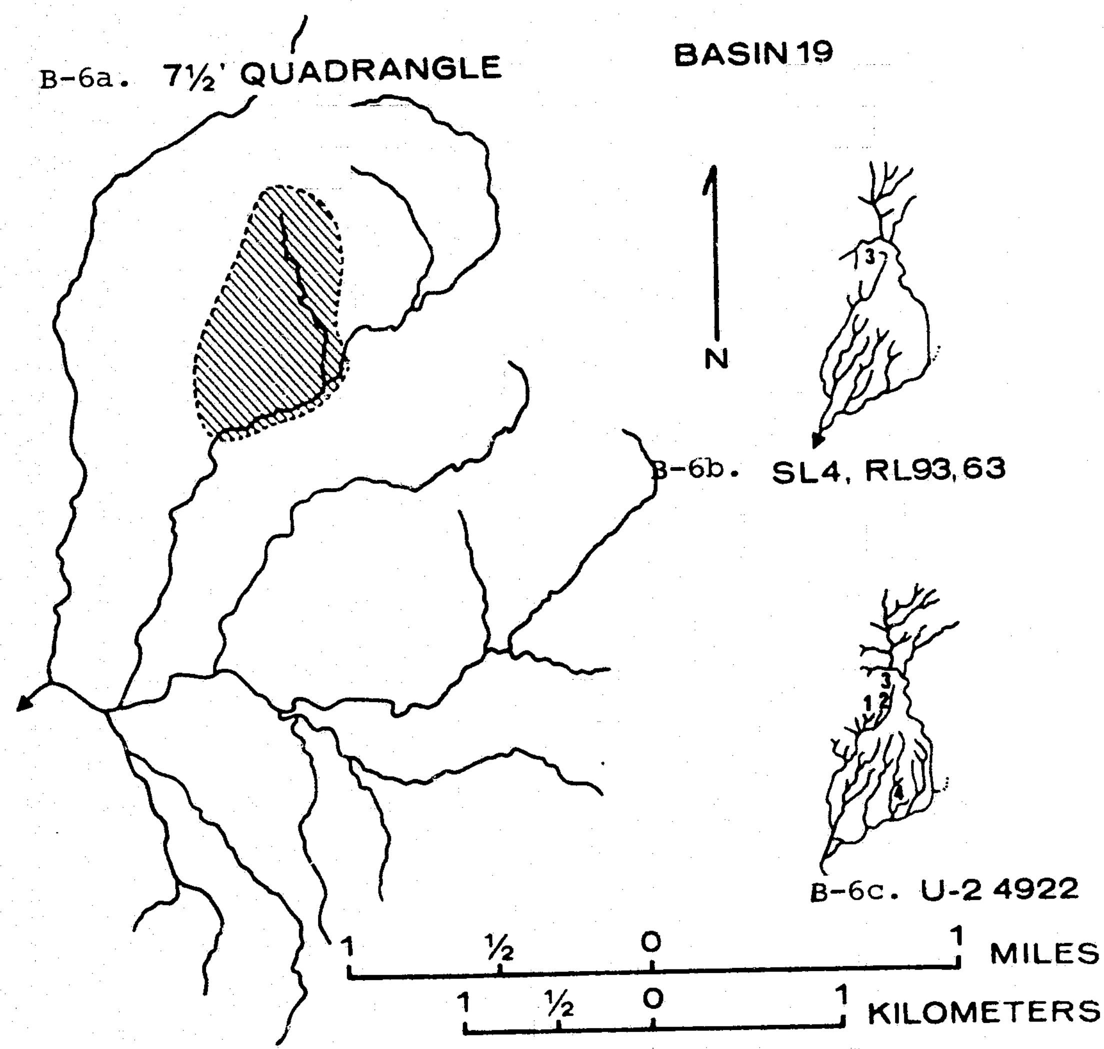


Figure B-6. THE DRAINAGE NETWORK OF BASIN 19 AS SHOWN BY THE SOURCES INDICATED. THE ENTIRE BASIN NETWORK IS SHOWN IN FIGURE 33a; DETAILS WITHIN THE SHADED PORTION ARE SHOWN IN 33b AND 33c.

3. Skylab shows the "hook" at the end of this wash; U-2 did not.

4. U-2 missed a first-order tributary into the tributary sketched; Skylab missed the latter tributary altogether.

Comments: Both the U-2 and Skylab frames compared typically missed as much as two orders of rills joining the networks drawn, however, these rills are typically very short and possess little definition in terms of distinct banks.

The U-2 shows more detail as a general rule; the detail, when sketched, is more accurately located.

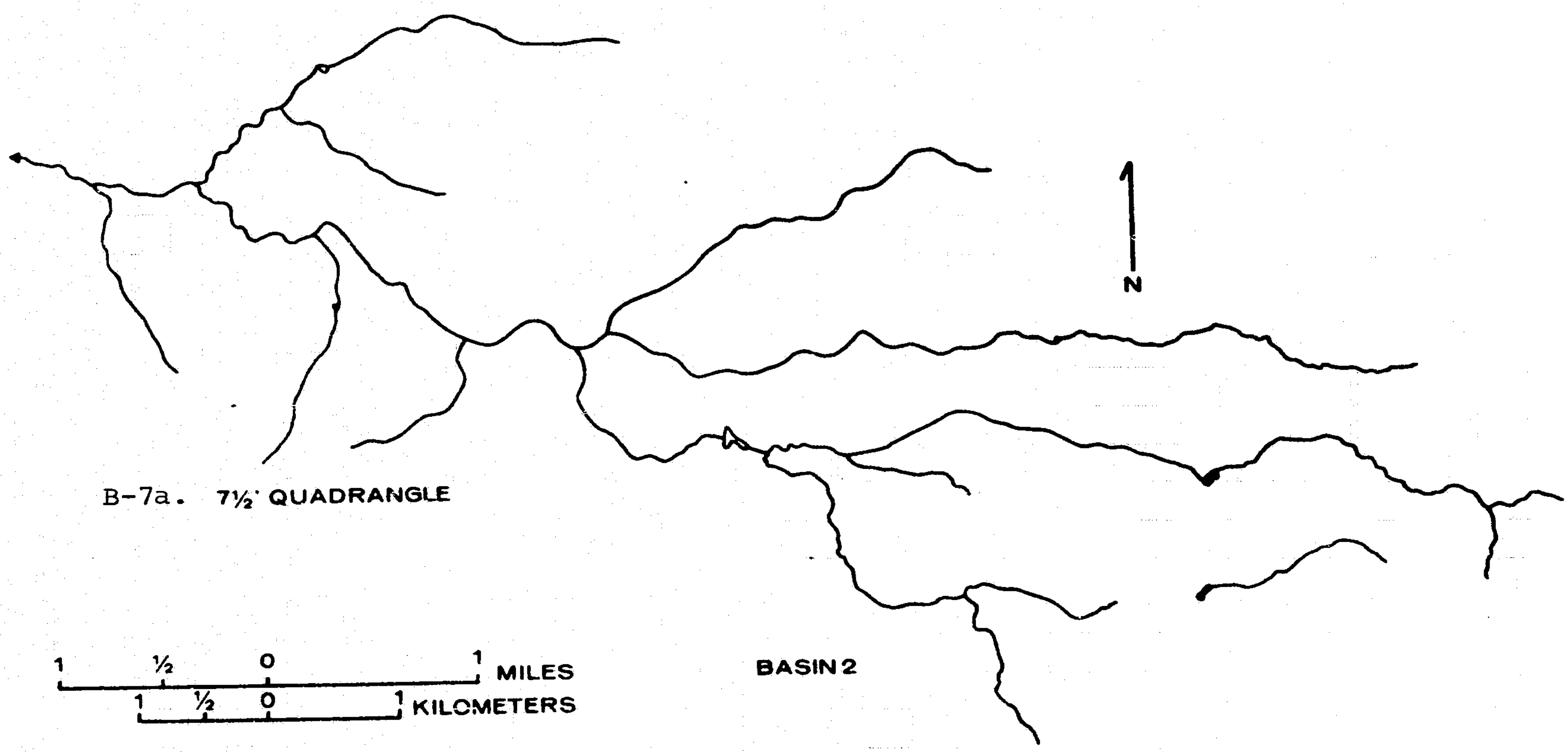
Noteworthy though, is the fact that in one place (point 3) Skylab revealed something that the U-2 did not.

Imagery: Some Comparisons that Lack Ground Truth

Basin 2 (Appendix Figures B-7a-B-7g):

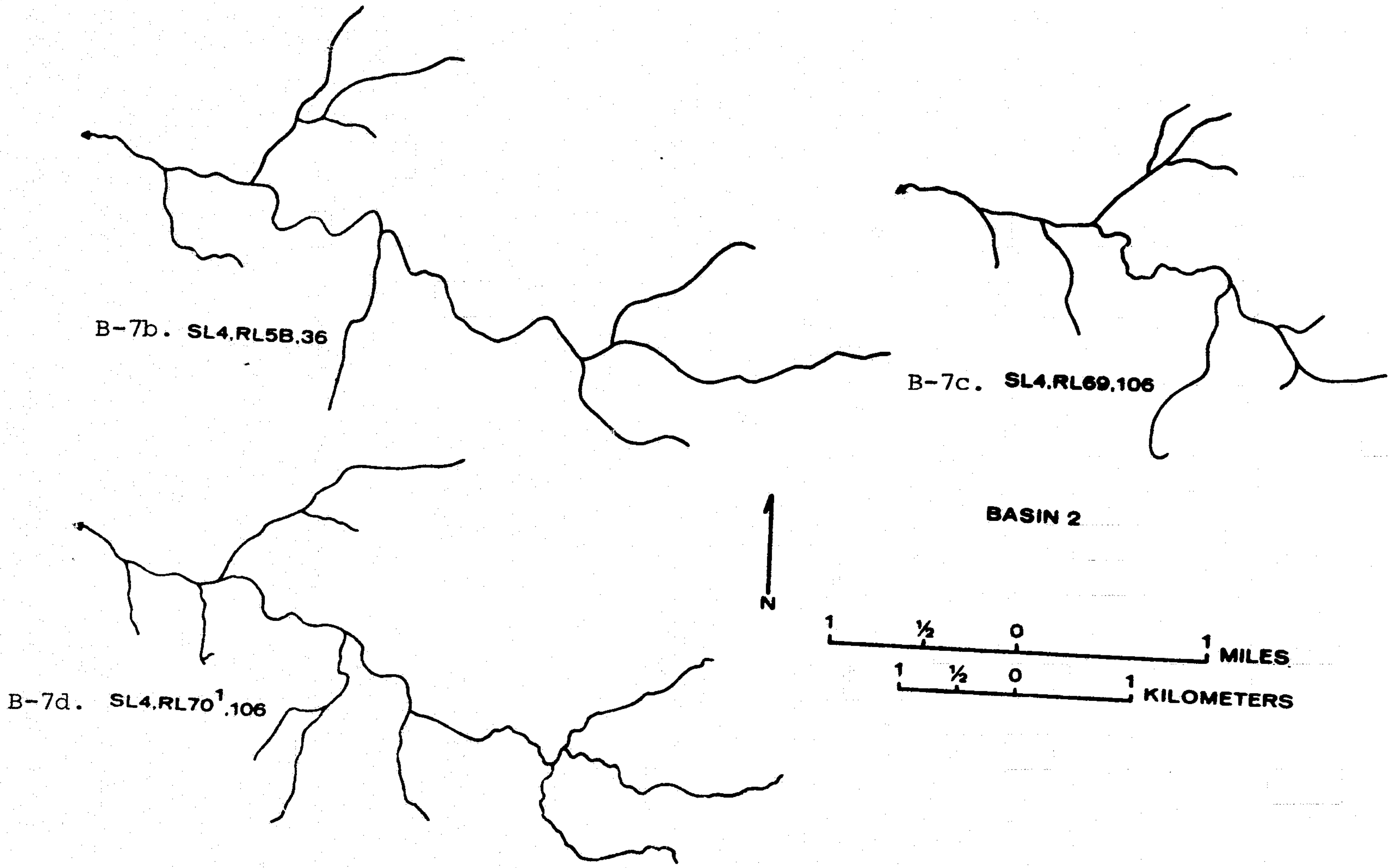
The drainage network of Basin 2 was drawn in its entirety using, in the succession given below, all of the photography that covered the basin. All renderings were done initially using the zoom stereoscope with a mylar overlay. The results are as follows:

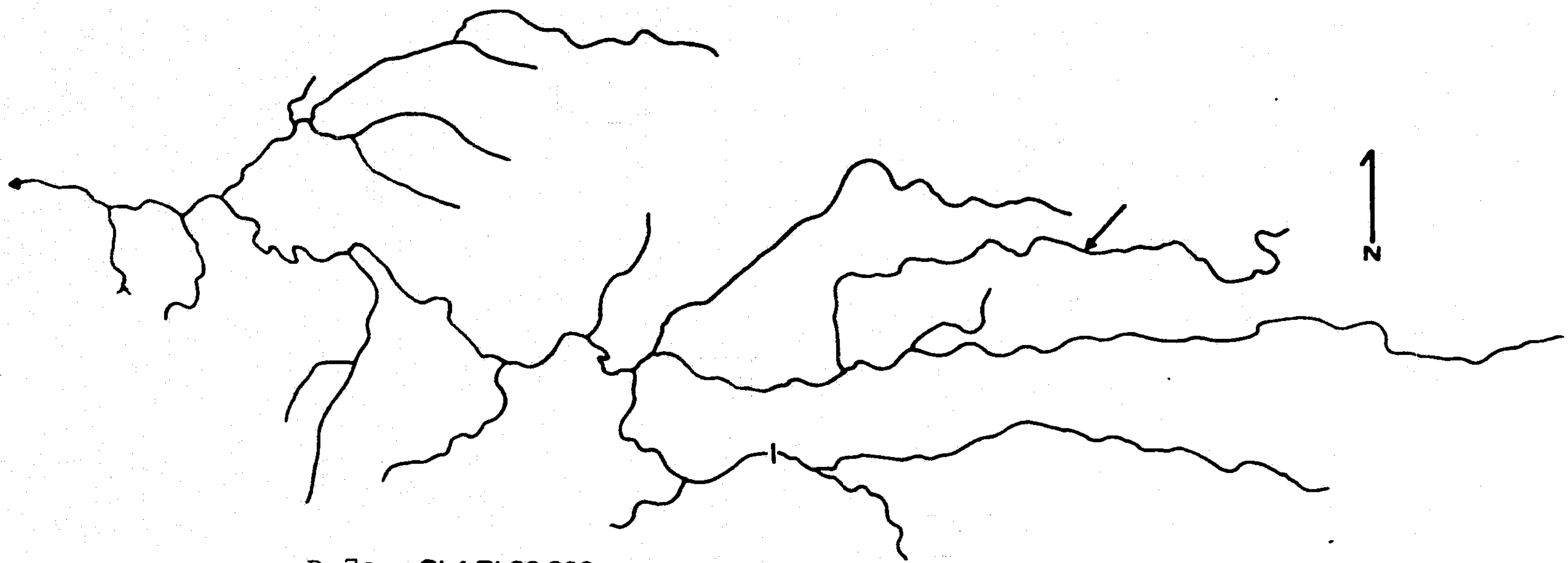
1. SL4, RL5B, 36-37 (Figure B-7b) -- The results are not too bad where relief is great. Note that the drainage



B-7a. 7½' QUADRANGLE

Figure B-7. THE DRAINAGE NETWORK OF BASIN 2 AS SHOWN BY THE SOURCES INDICATED. ALL FIGURES SHOW THE ENTIRE NETWORK REVEALED BY THE GIVEN SOURCE. THE ARROW ON FIGURE 34a POINTS OUT A DRAINAGE LINE THAT WAS DRAWN, BUT WHICH APPARENTLY DOES NOT EXIST.


B-7b. SL4,RL5B,36
B-7c. SL4,RL69,106
B-7d. SL4,RL70¹,106
N
BASIN 2
1 ½ 0 1 MILES
1 ½ 0 1 KILOMETERS

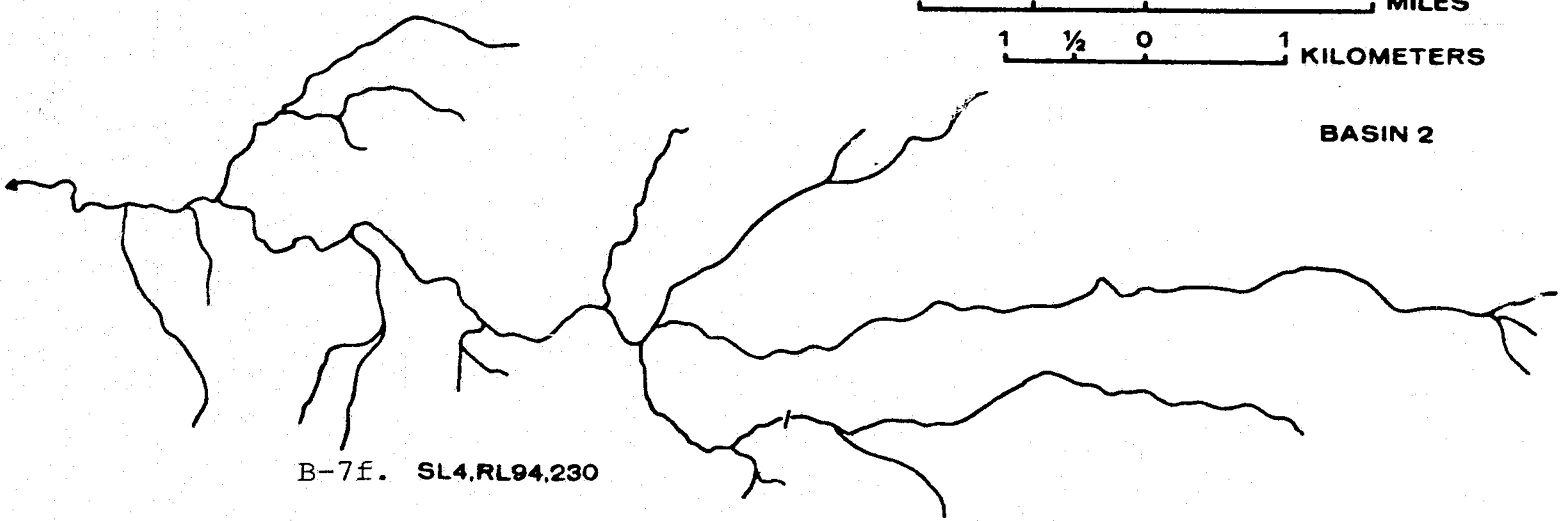


B-7e. **SL4,RL90,306**

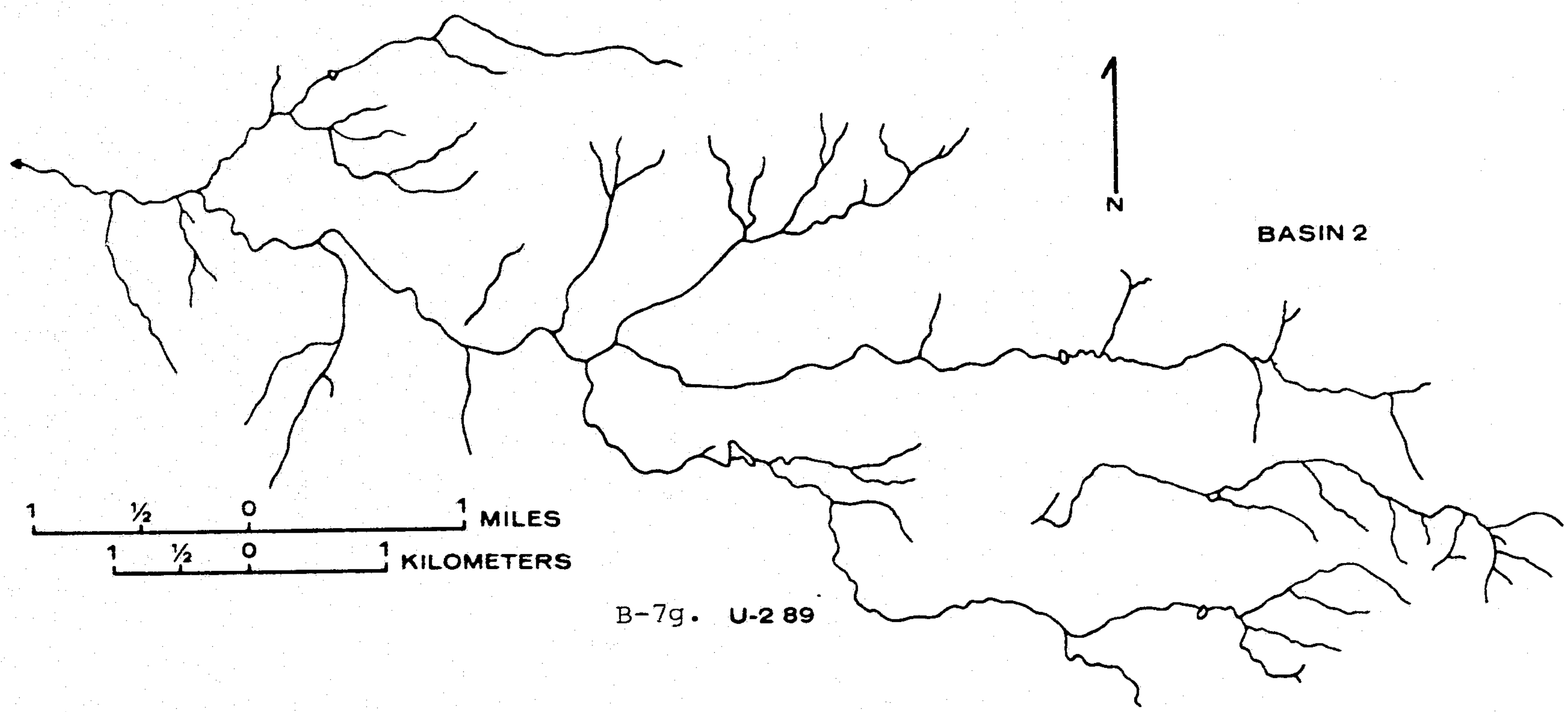
1 ½ 0 1 **MILES**

1 ½ 0 1 **KILOMETERS**

BASIN 2



B-7f. **SL4,RL94,230**



B-7g. U-2 89

network is not visible east of the point where the canyon is no longer incised; drainage lines on the plateau upland simply were not discernable.

2. SL4, RL69, 106-107 (Figure B-7c) -- The blue enhanced frames were the least valuable of all. Where relief is relatively small, drainage lines are not visible, moreover, the patterns drawn suggest that even where relief was relatively great, the drainage lines were not well located.

3. SL4, RL70[1], 106-107 (Figure B-7d) -- Approximately the same quality as number 1 above, except that fewer tributaries were shown.

4. SL4, RL90, 306-307 (Figure B-7e) -- A high quality photograph. The net drawn closely resembles that of the 7½ minute quadrangle in overall plan and in details. However, a few drainages were drawn that, on the basis of examination of the 7½ minute quadrangle and the U-2 generated network, seem to be incompatible with the topography and may not be real. The most blatant example of this is indicated by an arrow on Figure B-7e.

5. SL4, RL94, 230-231 (Figure B-7f) -- In some localities this frame seems more useful than the one discussed in number 4 above, in others, less useful. In general, there

were fewer cases in which seemingly erroneous decisions were made regarding location of the net using frames 230-231.

6. U-2 89-90 (Figure B-7g) -- The level of detail shown surpasses all the above, yet some decisions are open to question. Here, field checking would have been desirable, but was not done.

All of the above formats can be ranked in terms of their utility, from most useful to least useful, in the following order:

<u>Most</u>: U-2 89-90

SL4, RL94, 230-231 and SL4, RL90, 306-307, essentially comparable

SL4, RL70[1], 106-107 and SL4, RL5B, 36-37, essentially comparable

<u>Least</u>: SL4, RL69, 106-107

In general, the best of the Skylab photography increases the order number of the low-order drainage elements by one number; the U-2 boosts the order number typically by two.

Basin 5 (Appendix Figure B-8a-B-8c):

Two small portions of Basin 5 were drawn from U-2 frams 2657 (drainage net had been drawn on the photograph using the zoom stereoscope with a stereopair) and SL4, RL94,

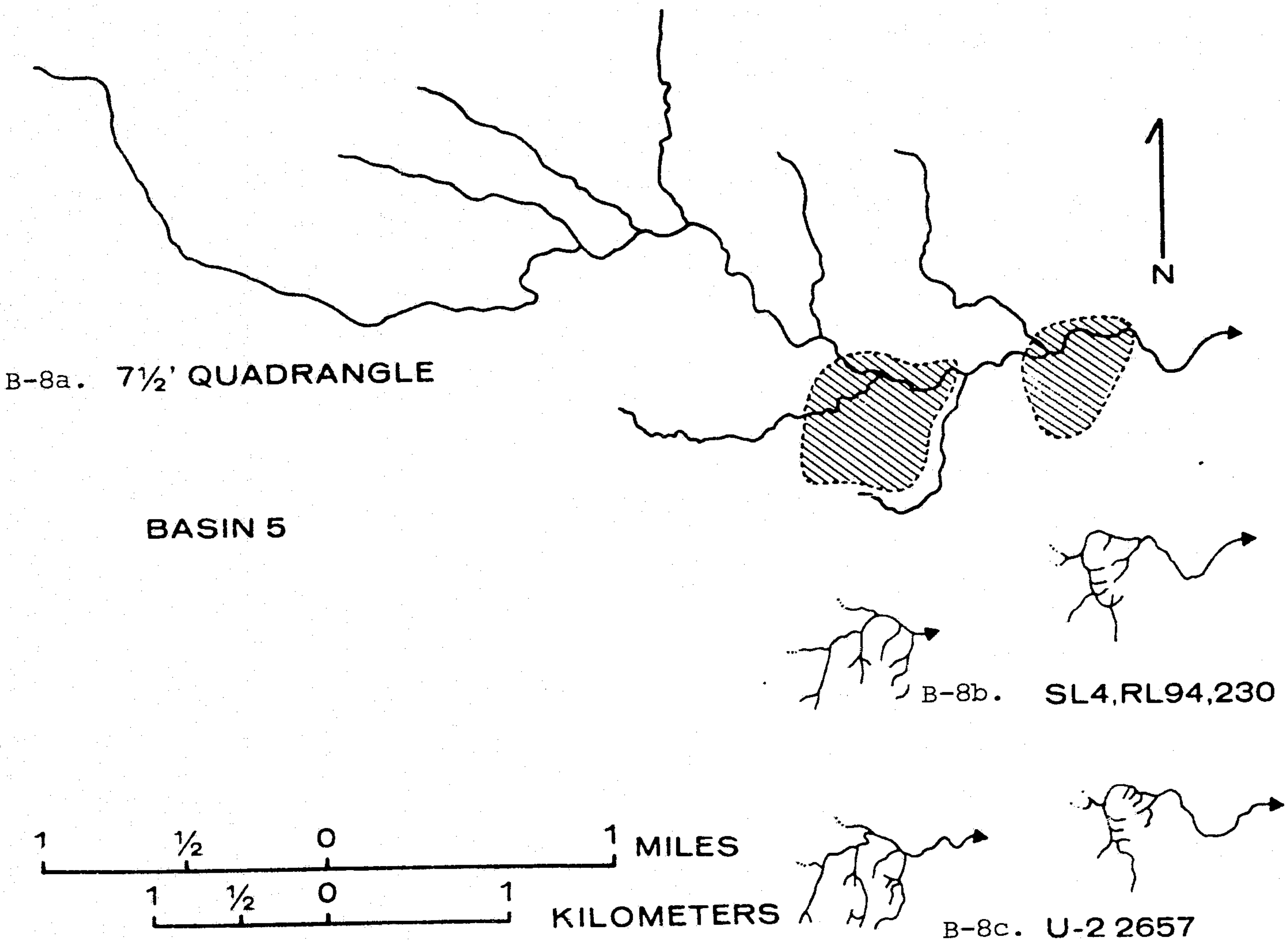


Figure B-8. THE DRAINAGE NETWORK OF BASIN 5 AS SHOWN BY THE SOURCES INDICATED. FIGURE 35a SHOWS THE ENTIRE BASIN; 35b AND 35c SHOW DETAILS OF THE SHADED AREAS. IMMEDIATELY ABOVE THEM ON 35a.

230 (zoom transfer scope only). As can be readily seen, there is only a small apparent difference between the results obtained by each of these two bases.

Basin 11 (Appendix Figure B-9a-B-9c):

One small portion of the headwater region of Basin 11 was drawn from U-2 frame 7581 and from SL4, RL94, 230. Both were drawn using only the zoom transfer scope. The difference in detail shown is self-evident. The Skylab frame typically adds one number to low-order elements of the network, the U-2 frame typically adds two numbers.

Basin 18 (Appendix Figure B-10a-B-10b):

A small portion of Basin 18 was drawn using U-2 frame 4922, on which drainage lines had been drawn via the zoom stereoscope with a stereopair. It is included here because the apparent detail shown by the U-2 is enormous, and increases stream order numbers by three.

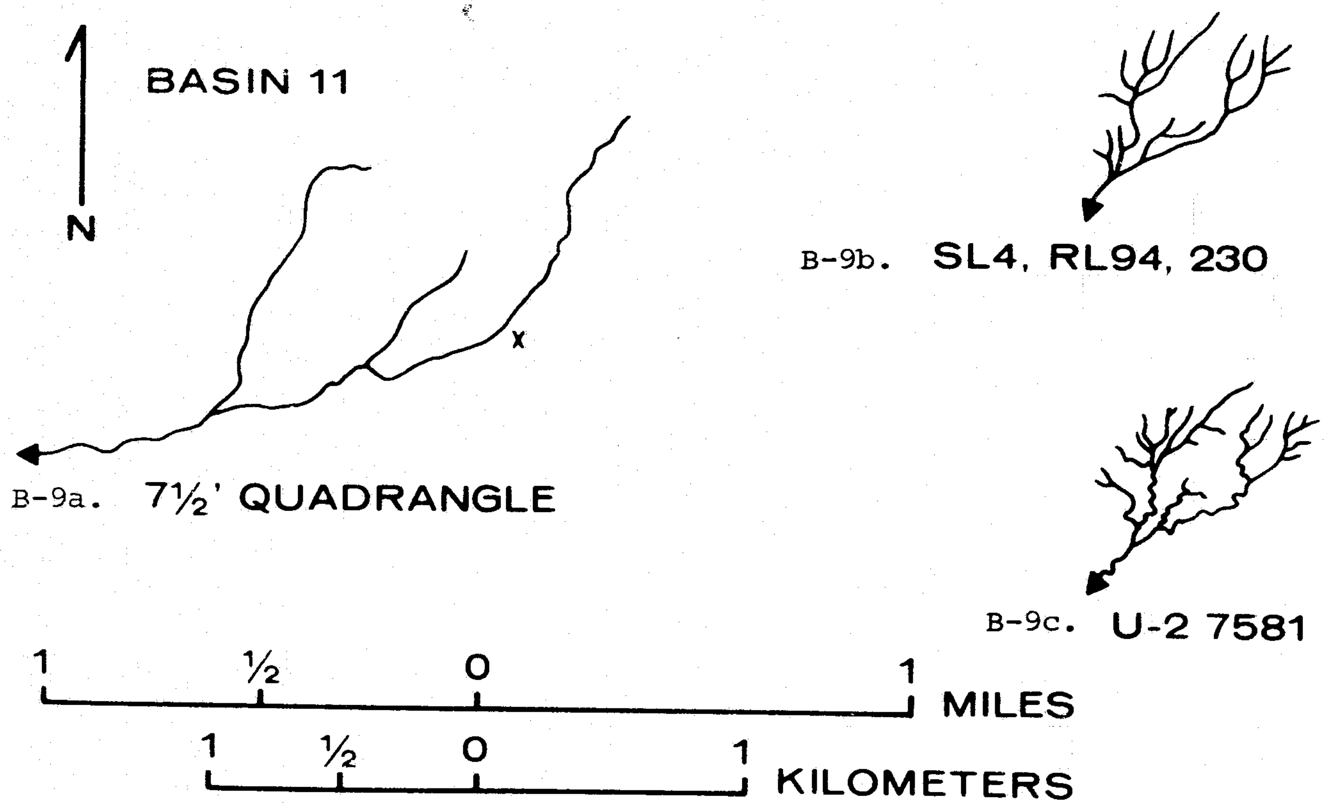


Figure B-9. THE DRAINAGE NETWORK OF BASIN 11 AS SHOWN BY THE SOURCES INDICATED. FIGURE 9a SHOWS THE ENTIRE BASIN NETWORK; 9b and 9c SHOW DETAILS OF THAT PORTION UPSTREAM FROM POINT "X" ON 12a.

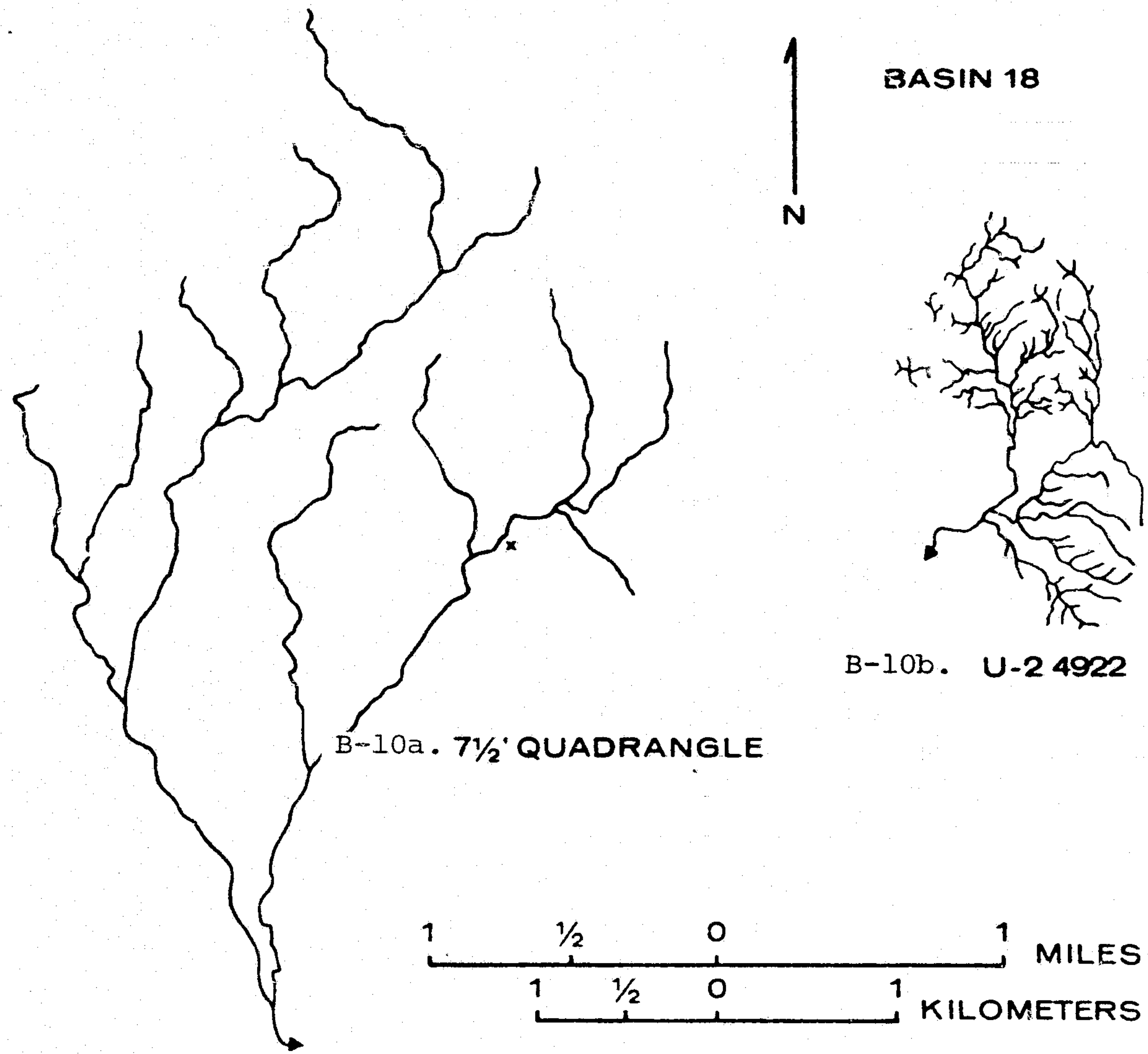


Figure B-10. THE DRAINAGE NETWORK OF BASIN 18 AS SHOWN BY THE SOURCES INDICATED FIGURE 37a SHOWS THE ENTIRE BASIN NETWORK: 37b SHOWS DETAILS OF THAT PORTION UPSTREAM FROM POINT "X" ON 37a